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COOPERATIVE SNOW INVESTIGATIONS

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Forest Service
Rocky Mountain Forest and
Range Experiment Station

Department of the Interior
Bureau of Reclamation
Branch of Project Planning
Hydrology Division

PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST

REPORT NO. 1
THE 1948 SNOWMELT SEASON

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NOVEMBER 1949

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The 1948 Snowmelt Season

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Sanborn B-864

Byers Peak (elevation 12,790 feet above sea level) in winter. This is an excellent general view of the Fraser Experimental Forest. The town of Fraser is located in the meadow visible in the center of the picture. It lies off the right-hand edge. Byers Peak is the divide for the Fraser Experimental Forest. The wind tower and other installations are found in the valley beyond the second ridge along the right-hand edge, as counted from the meadow. The adherence of masses of snow to the trees is characteristic of this high-altitude, Rocky Mountain country. It may serve to explain why trouble has been experienced with the operation of the Sacramento-type, seasonal storage precipitation gages. Photograph reproduced with the permission of the copyright owner: the Sanborn Souvenir Co., Inc., Denver 11, Colorado.

PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST THE 1948 SNOWMELT SEASON

A. Introduction

The cooperative snow investigations reported upon in this progress report are being conducted by the Bureau of Reclamation and the Forest Service, at the Fraser Experimental Forest near Fraser, Colorado, under the general supervision of J. R. Riter, Chief, Hydrology Division, Branch of Project Planning, Bureau of Reclamation, United States Department of the Interior, Denver, Colorado; and W. G. McGinnies, Director, Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Fort Collins, Colorado. This progress report was prepared by Phyllis Peasley, Mathematician; Walter U. Garstka, Hydraulic Engineer, Bureau of Reclamation, Denver, Colorado; and Bertram C. Goodell, Conservationist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

The Fraser Experimental Forest is located about 5 miles south of the town of Fraser, Colorado, and about 75 miles west of Denver, Colorado. The Fraser Experimental Forest lies wholly in the drainage basin of St. Louis Creek in the Colorado River Basin. The area of the drainage basin above the St. Louis Creek gaging station is 32.8 square miles. A general view of the Fraser Experimental Forest is shown on Photograph Sanborn B-864. The Fraser, Colorado, quadrangle shows the topography of the Forest, which has an altidudinal range of from about 9,000 feet to 12,790 feet above sea level. The location of installations specifically used in this cooperative snow investigation is shown on Map CS-SLC-35. Chart CS-SLC-32 shows the area-elevation relationship of the St. Louis Creek drainage area above the gaging station near Fraser, Colorado.

The history of certain Forest Influences investigations which the Forest Service has been conducting in the Fraser Experimental Forest is given in detail in Reference 10.

The Bureau of Reclamation's interest in this cooperative investigation stemmed from the desire for improving the accuracy of both seasonal water yield and rate-of-run-off forecasts for use in both planning and operation of Reclamation projects; and from the need for more precise information about the rates of run-off from snowmelt for use in flood design studies and computations.

The objectives of the Bureau of Reclamation's participation in the Cooperative Snow Investigations were stated as follows in Reference 3:

"a. A valid measurement of total winter precipitation.

b. A valid determination of snow storage water equivalent as shown by snow surveys.

c. Development of a method permitting the rapid evaluation of heat availability to a reasonably attainable and practically applicable standard of accuracy.

d. Development of a technique capable of routine use first to account for, and second to forecast losses from snow storage, which may occur either as snowmelt or as evaporation."

A method of forecasting and synthesizing rates-of-runoff from snowmelt is needed for planning of irrigation projects and operation of reservoir and river systems. The aim is to develop a rapid method based upon data of an impersonal nature, which can be readily secured at low cost for the purpose of forecasting rates of run-off from snowmelt within practically significant limits of accuracy.

This progress report deals with five subprojects:

(1) Observations of the performance of Weather Bureau design Sacramento-type shielded precipitation storage gages.

(2) Investigations of methods of interpreting the commonly available daily maximum and minimum temperatures in terms of degree-days above 32° F.

(3) Analysis of rates of snowmelt.

(4) Calculation of evaporation losses from the snow blanket during the snowmelt season.

(5) Synthesis of a rate-of-run-off from snowmelt hydrograph.

Basic data used in the preparation of this report are given in Appendix I.

B. Observations of the Performance of Sacramento-type Shielded Precipitation Storage Gages

The performance of the Weather Bureau Design, Sacramento-type shielded seasonal-storage precipitation gages is summarized in Appendix II; Tables CS-T4-A for the 1947 and 1948, and CS-T6, for the 1949 seasons. It is evident on inspection of the table for 1947 and 1948 and a study of the photographs taken at the time the various gages were measured that the gages did not indicate very well the precipitation accumulated during the winter season as judged by the comparison between the water equivalent gage increment and the water equivalent as surveyed by a 10-sample snow course in the vicinity of the gage. In 1949 there seemed to be a closer agreement between the shielded gage increments and snow water equivalent on the ground than had been the case in 1947 and 1948. This may be due to the fact that the

snows of the winter of 1948-1949 fell at low temperatures as dry snows and, therefore, did not stick to the gages and shields.

The seasonal precipitation trapping effectiveness of the gages was judged by a comparison of the April 1, 1947, 1948, and 1949, surveys. The May 1 surveys cannot be interpreted in this manner since they report only the increment for the month of April.

The installations were made in the Autumn of 1946. At that time, material was not procurable for the construction of supporting towers out of angle irons. The gages were, therefore, installed upon wooden towers. The not wholly satisfactory behavior of these gages might presumably be ascribed to the wooden towers.

Although the installations are admittedly not perfect, nevertheless, the behavior of these gages during the snowstorm of June 14, 1947, indicates that the gages were put out of commission by the accumulation of snow in the hopper created between the converging slats of the Alter Shield and the diverging sidewalls of the storage gage body. Photograph No. 110-CF-237 taken June 14, 1947, shows the East St. Louis seasonal storage precipitation gage of the hundred-inch-capacity, Sacramento-type with Alter Shield. This snow had a depth of 14 inches and a water equivalent of approximately 2 inches. This fall was sufficient to immobilize the shield. Subsequent snowfalls would without a doubt have completed the capping over of the mouth of the shield. This may be the chief reason why the observations recorded in the table for 1947 and 1948 turned out as they did.

One possible reason why the shields and Sacramento-type gages have not performed adequately under Rocky Mountain conditions is that many of the snowstorms in Colorado fall at times of very low wind velocities. Furthermore, the gages are sheltered in the woods in lodgepole pine and spruce-fir type forests. The protective effects of the tree growth are evidently so potent that there is practically no wind blowing within the crown-canopy zone at the time of the snowfall. Therefore, the shield on the storage gage is not called upon to perform any useful service, it merely acts as a ledge upon which snow can accumulate.

It appears that much of the emphasis upon shielding of seasonal storage precipitation gages and upon aerodynamic streamlining of the gages themselves has not taken cognizance of the fact that wet snow sticks to practically anything. Observations of accumulation of snow of up to several inches in diameter which have come to rest upon telephone wires are not uncommon. Vertical surfaces of buildings and vegetation have at times held a heavy accumulation of sticky, wet, snow. The spectacular beauty of the lodgepole pine forest shown in Photograph Sanborn B-864 illustrates the clinging quality of wet snow. When air temperatures and moisture contents of the snow crystals favor stickiness of snow, accumulation will take place with no regard to the precision of streamlining and of shielding of precipitation storage gages.

Photo No. 110-F-1677-A April 3, 1947

St. Louis Pass gage located at an elevation of about 10,950 feet. This is a 200-inch capacity, Sacramento-type seasonal storage precipitation gage. J. L. Goodson is in the photograph. The water equivalent gage increment since October 25, 1946, was 21 inches as compared with a snow-water equivalent on the ground, as determined by 10 samples taken in the vicinity of the gage, of 23.11 inches. It is interesting to note the blanket of snow on the platform and the cylinder of snow extending into the shield. It appears from the character of the accumulation of this snow that the cylinder within the shield was formed by snow packing down from within the shield and not by snow building up from the platform. Fraser Experimental Forest, Fraser, Colorado.

Photo by Clifford Myers, Forest Service.

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Photo No. 110-CF-237 June 14, 1947

East St. Louis Creek seasonal storage precipitation gage, 100-inch capacity Sacramento-type, with Alter Shield, as it appeared after the snowfall of June 14, 1947. The snow had a depth of 14 inches and a water equivalent of approximately 2 inches. This was sufficient to lodge in the space between the shield and the gage.

Photo by Bert Goodell, Forest Service.

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Photo No. 110-CF-238 April 1, 1948

East St. Louis Creek gage, Fraser Experimental Forest, Fraser, Colorado. This is a 100-inch capacity, Sacramento-type, seasonal storage precipitation gage installed at an elevation of about 9,650 feet. Water equivalent gage increment since September 25, 1947, the date of servicing, amounted to 12.50 inches as compared with 14.35 inches, determined with a 10-sample snow course surveyed in the vicinity of the gage.

Photo by Bert Goodell, Forest Service.

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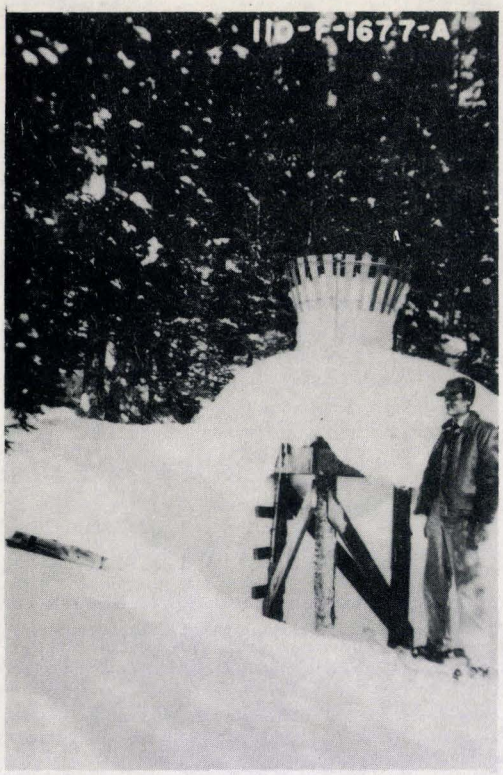
Photo No. 110-CF-252 April 1, 1948

Snow survey being performed at the West St. Louis Creek seasonal storage precipitation gage in the Fraser Experimental Forest near Fraser, Colorado. The water equivalent increment in the gage since September 25, 1947 amounted to 18.00 inches as compared with 20.25 inches water equivalent as determined by a 10-sample snow survey performed in the vicinity of the gage.

Photo by Bert Goodell, Forest Service.



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110-CF-252

The snow-entrapping effect of the space between the shielded gage and the Alter Shield is shown on Photograph 110-F-1677-A, taken April 3, 1947, of the St. Louis Pass Gage, located at an elevation of about 10,950 feet.

Another Photograph, No. 110-CF-238 taken April 1, 1948, shows the appearance of East St. Louis Creek Gage, located at an elevation of about 9,650 feet.

Further thought is being given to the storage gage problem since there is a very definite practical application of precipitation storage gage records. Even though a storage gage may not be of much use for the measurement of the total winter season's precipitation, nevertheless, a record of rainfall and snowfall which may occur during the month of March and during the month of April would give a potentially very useful additional variable to be used in the calculation of seasonal water yield forecasts. At the present time, a snow survey as of April 1, discloses the snow water equivalent in storage. A snow survey as of May 1, may disclose some other amount of snow in storage, however, during the month of April, a certain amount of melt may have occurred and a certain amount of snow and rain may have fallen. The snow survey in itself does not indicate at all what the net balance is between the snowmelt and evaporation and the precipitation which occurs during the month of April. With accurate melt-season monthly increments, some improvement in the accuracy of the seasonal water yield forecast might be attained in a number of drainage basins where significant amounts of snowmelt occur during the month of April.

C. Investigation of Methods of Interpreting the Commonly Available Daily Maximum and Minimum Temperatures in Terms of Degree-Days Above 32° F

The purpose of this part of the investigation is to determine a more accurate evaluation of heat from air temperature in connection with snowmelt studies, especially with reference to project planning investigations which are limited primarily to daily maximum and minimum temperature data.

Charts and tables prepared in this study are listed and presented in Appendix III. The charts showed linear or curvilinear relationship between degree-days above 32° F as computed from hourly hygrothermograph records and the maximum or average of the maximum + minimum temperature records of the stations studied.

Computations of lines by the least squares method as exemplified by Charts CS-FH-29 and CS-FH-33 were made of all dispersions that had sufficient data, except for those charts which showed curvilinear relationships.

Results of the various correlations are summarized on composite charts, illustrated by Charts CS-FH-44, and CS-FH-45, which show monthly comparisons of the slope variations. The mean lines were plotted for each month and their equations are expressed mathematically on the charts. An additional tabulation of these results is shown on Table CS-T2. The total number of correlations studied in this connection is indicated by the number of entries in Table CS-T2.

The departures from the ratio of actual run-off to that computed using degree-days from the hygrothermograph trace are given on Table CS-T1 for the major 1948 snowmelt period. The comparisons indicate that a lower percentage departure resulted from using degree-day values derived from the charts.

In view of the good correlations obtained, it is believed that degree-day values derived from these charts may express more accurately the heat factor for application in run-off forecasts and in project planning snowmelt studies than straight arithmetic averages of available temperature data.

D. Analysis of Rates of Snowmelt

The period of record chosen for use in a correlation of the meteorological factors involved in snowmelt with volumes and peak rates of run-off in St. Louis Creek near Fraser, Colorado, was May 14, 1948, to June 5, 1948, inclusive, with the exception of May 17, 18, 25, and 26 because on those days some of the necessary data were missing. The reason for the choice of this period was that before May 14 there seemed to be some ice effect in the streamflow records and after June 5 it was thought that much of the snow in the basin was disappearing. Hourly values of basic data available for the period are temperature and relative humidity records for two stations in the basin, wind records at two levels in the forest and three levels at the open site, and solar radiation records at Shadow Mountain Solar Radiation Station near Grand Lake, Colorado.

In order to determine the time lag, or length of time that elapses between the presence of melt conditions and the appearance of that melt as run-off measured in the stream, the plotting of hourly temperatures from the hygrothermograph station at the Fraser Headquarters Station was compared with an hourly plotting of cfs flow in St. Louis Creek near Fraser, Colorado. There seemed to be approximately a 6-hour displacement between the peaks of the temperature curve and the peaks of the run-off curve. The time lag then could be 6 hours plus a multiple of 24, but observations of men working in the field indicated that the lag was about 6 hours. This determination of the lag time was further substantiated by the fact that the lag time of Fool Creek, one of the tributaries of St. Louis Creek, was only 3 hours and comparing the difference in drainage areas and the distance from Fool Creek to the gaging station on St. Louis Creek, it seemed logical that the lag time for the larger area should be about twice that of the smaller area.

Photo No. 110-CF-236 April 1949

Fraser Experimental Forest near Fraser, Colorado. Wind tower installation in the open. The hygrothermograph shelter is seen near the left-hand margin. The low anemometer mounted on an adjustable support is seen just to the left of the M-7 snow vehicle. To the right of the tower is the shelter housing the wind direction and velocity recorder. Another wind tower is located in the woods off the right-hand edge of the photograph.

Photo by Bert C. Goodell, Forest Service

The hydrographs of St. Louis Creek near Fraser, Colorado, together with recorded precipitation at the town of Fraser, Colorado, for the period 1935 to 1948, inclusive, are plotted on Charts CS-SLC-28, A through N, of which only Chart CS-SLC-28-N is presented in Appendix IV as an example.

Yesterday's flow in cfs of St. Louis Creek was plotted against today's flow using only days of falling stages for the 1948 run-off season and some values from the 1947 season to give a recession factor. This factor as computed from the slope of the line was 0.933 for stages above 30 cfs and 0.981 for stages below 30 cfs as shown on Chart CS-SLC-6. Chart CS-SLC-33 shows the standard recession curve plotted by days. This standard recession curve fits the hydrographs of St. Louis Creek for the period 1935 through 1948.

A similar determination was made for Fool Creek, a tributary of St. Louis Creek. Fool Creek has a drainage area of 709.1 acres, or 1.11 square miles. An analysis of recession for 1947 yielded a factor for a 24-hour period of 0.871 for flows of about 14 cfs. This factor increased gradually to a value of 0.963 at 0.105 cfs. The recession curve as based upon the 1947 snowmelt season fitted all years of record, from 1940 to 1948, inclusive, except for 1944, when the volume of flow was the lowest of record. Chart CS-FC-2 shows the extension of the end of the hydrograph for each day using this recession curve.

The plotting of the recession curve for St. Louis Creek was used to extend the end of the hydrograph for each day, shown on Chart CS-SLC-23. This was based on the premise that the peak alone does not indicate the total melt for a day but rather it is that peak plus the area indicated by the recession. The melt or run-off of 1 day then was considered as the area under the peak plus the area of the wedge formed by the recession lines of the day itself and the previous day. This analysis of the snowmelt hydrograph is based upon field experience in observing run-off from snow-melt. There is, in effect, no overland flow from snowmelt, practically all run-off entering stream channels as subsurface or groundwater flow, usually as a combination of both.

Various methods were employed to compute the amount of run-off attributable to 1 day's melt conditions. An attempt was made to use equations to compute this value but all the ones found were derived to figure the volume of a recession with a constant recession factor and not one whose base line was complicated by the use of more than one recession factor as was the case in our problem.

The volume of the peak on the individual day was determined by the use of a planimeter, then a method of averages was used to approximate the value of the wedge-shaped recession until both lines have reached 8 cfs which was considered the base flow. The values obtained for the two parts of the melt were then added together to give the figure used as the melt or run-off computed from the hydrograph.

In order to check the accuracy of the results obtained by using averages, a method of computing the values through the use of calculus was derived. As it was found that the values obtained for the days checked agreed quite favorably, it was thought the values obtained by averages were sufficiently accurate for this study. These values also compared very well with the values obtained by using the planimeter to determine the area of a few of the days at the beginning of the snowmelt period.

The following table shows the comparison of the volume, obtained by the various methods, of the part of the wedge from the end of the first day to the point where the recession factor changes. The calculus-derived volume does not agree as exactly with the planimeter value as it should because it was applied to the nearest whole day instead of making a correction for the fractional parts of days cut off by the joining of the recession curve to the run-off hydrograph.

Date	Volume determined by 5-day averages	Volume determined by calculus (Approx.)	Planimeter
May 15	118.01 A.F.	119.73 A.F.	106.03 A.F.
May 22	271.48 A.F.	275.41 A.F.	292.73 A.F.

For the calculus method of deriving the volume between two recession curves see Table CS-T5 by Engineer P. M. Ford of the Bureau of Reclamation.

Using the melt as computed from the hydrograph as the run-off for the day, a simple correlation of run-off and degree-days above 32° F computed from the hygrothermograph trace was plotted on Chart CS-SLC-9. The correlation coefficient was figured and found to be r = 0.579.

1. The statistical approach. As there are a large number of factors interacting to produce the run-off as measured in the streams, it was decided to try a multiple correlation analysis in an attempt to develop a method of forecasting the run-off. Degree-days above 32° F, degree-days above 50° F, solar radiation, dew point temperatures, relative humidity, wind at the 47.4! level in the open, and at the 1.4! level in the forest as independent variables and the run-off computed from the hydrograph were used in various combinations to develop a forecasting equation. The way these variables correlate individually with the run-off is shown in charts available on request: CS-SLC-11, CS-SLC-16, CS-SLC-17, CS-SLC-20, CS-SLC-30, and CS-SLC-31. Table CS-SLC-T15 shows the various multiple regression coefficients and the equations obtained together with the correlation coefficients and the standard deviations of residuals for each set of variables.

The equation designated "e" in Table CS-SLC-T15, yielded the highest coefficient of multiple correlation R = 0.736. Equation "e" is based upon degree-days above 32° F, relative humidity percent, both from the hygrothermograph at the Fraser Headquarters, and miles of wind total for a day at the 47.4 ft. level from the wind tower in the open. All three

values are in terms of calendar-days. As there is usually practically no snowmelt at night, the time lag of run-off is taken care of tacitly in the interaction accounted for in a multiple correlation computation.

The fact that the correlation coefficients were not very high indicates that additional study is required for a better determination of the amount of run-off caused by the melting conditions of 1 day. It is obvious that all the contributing factors have not been accounted for. Possible explanations are that they are not measured in the area, the measurements themselves are not adequate, the quantities measured were not used in the right combination, or the functions derived from the measured quantities did not make the best possible use of the data.

It is interesting to note that solar radiation yielded negative regression coefficients whenever it was introduced into a multiple correlation. This may indicate that high average daily intensities of solar radiation are correlated also with high rates of evaporation of snow, rather than only with high rates of water releases from snowmelt, insofar as is indicated by the factors studied in the Fraser Experimental Forest.

2. The physical approach. Another approach to the analysis of snowmelt was that of applying a physical equation. The one developed by Phillip Light in Reference 7 was used. His equation was adjusted when applied to the instrumentation in the Fraser Experimental Forest to the form in B of Chart CS-SLC-36.

A necessary condition for applicability of the reduced form of Phillip Light's eddy-conductivity equation, in which wind velocity at only one level is introduced, is that there exist a logarithmic distribution of wind velocity with height. The wind records from anemometers at three levels of the wind tower in the open were analyzed for the 1948 snowmelt run-off period. Chart CS-WT-4 presents, on semilogarithmic paper, wind in relation to height for certain 6-hour periods for May 13 to 23, 1948. Chart CS-WT-5 similarly presents lines for wind in relation to height by 24-hour periods for May 14 to June 5, 1948, inclusive. The individual lines on both charts disclose the requisite logarithmic distribution. There is evident a surprising parallelism in the slopes of the lines for the various periods.

The distribution of wind velocity with reference to height, as indicated by the mean line on Chart CS-WT-5, is expressed by the following equation:

$$Y = 0.0474e^{0.060x}$$

in which Y represents height of anemometer above ground in feet and x represents miles of wind, total for a 24-hour period.

The air temperature in Light's equation at the wind tower in the open was used directly without adjustment for lapse rate within the Fraser Experimental Forest. No lapse rate adjustment was made because field observations have disclosed that, although snow accumulation takes place by

elevation zones, snow disappearance in a mountainous region takes place by aspects. This is substantiated by the observations reported by Daniels in Reference (2:185-186).

The data used in Light's equation are from the wind-tower and hygrothermograph installations on West St. Louis Creek shown on Photograph 110-CF-236. Table CS-SLC-T22 shows the computation of evaporation and melt by Light's equation. The results of the application of Light's equation to run-off computation are given in Table SC-SLC-T11.

A comparison of the inches of run-off computed from Light's equation and calculated from the multiple-correlation equation "e" with those computed from the hydrograph is given in Table CS-SLC-T17.

The basic coefficient K for Light's equation for St. Louis Creek for 1948 was found to have a value of 0.926.

A computation of daily snowmelt run-off as shown on Chart CS-FC-2 was made for Fool Creek, using the same techniques as shown on Chart CS-SLC-23. Snowmelt run-off volume computations were made for a period of 15 days and the comparison of the run-off thus computed with water yield calculated by Light's equation is given in Table CS-FC-T4.

E. Calculation of Evaporation Losses from the Snow Blanket During The Snowmelt Season

Light's equation permits differentiation between snow melting and snow evaporation. If the value of e, the average vapor pressure in millibars, in the expression (e-6.11) is less than 6.11, the expression becomes negative, indicating evaporation.

If the temperature is less than 32° F, the expression (T_f-32) becomes negative. When this occurs, the 6.11 may need to be changed to the value corresponding to the actual temperature.

Table CS-SLC-T24 in Appendix V shows the evaporation loss as calculated for 1948 by Light's equation both including and excluding 6-hour periods during which the average temperature was below 32° F.

It was found that, for the 20 days used in the computation, total evaporation exclusive of periods having average temperatures below 32° F was 1.61 inches. Total evaporation for the 20 days, including periods having average temperatures below 32° F not corrected for vapor pressure corresponding to the average temperature dew point, was 1.79 inches. The exactly computed evaporation would fall somewhere between the 1.61 and 1.79 inches, for the 20 days.

This computed value is in close agreement with the evaporation losses of from 1.33 to 2 inches for the snowmelt season as measured and calculated at the Fraser Experimental Forest and presented on Table 3 of Reference 10.

Table CS-SLC-T29 shows the evaporation loss as calculated by Light's equation for the period when data are available in 1949. For similar periods of record, the losses in 1949 appear to be less than those computed for the 1948 season.

Time has not permitted an analysis of the evaporation losses from the snow from the beginning of the operation of the installations in the spring, instead of only during the so-called snowmelt season, but such an analysis is in progress and results will be reported upon subsequently.

F. Synthesis of a Rate-of-run-off from Snowmelt Hydrograph

The high degree of agreement between the totals of snowmelt run-off as computed from the hydrograph and as calculated by Light's equation suggested the possibility of synthesizing a snowmelt run-off hydrograph for St. Louis Creek.

An inspection of the areas and shapes of each day's snowmelt run-offs on Chart CS-SLC-23 disclosed certain relationships which were plotted individually on Charts CS-SLC-24, 10, and 25. For each relationship a least squares line was computed.

Chart CS-SLC-24 shows the relationship between the total computed melt for 1 day and the volume of the section, for the first day, designated as Area 1, on Chart CS-SLC-27. The ratio of the average of these two quantities is 0.119. This condition indicates that about 12 percent of the total volume runs off on the first day and the rest does not appear as measurable run-off until later.

Chart CS-SLC-10 shows the relationship between the volume of section for the first day and the height in cfs to the peak from the recession line of the previous day, the distance designated A-B on Chart CS-SLC-27.

Chart CS-SLC-25 shows the relationship between the volume of section for the first day and the height to the trough from the recession line of the previous day, the distance designated C-D on Chart CS-SLC-27.

Taking into account lag time and the recession factor as determined for St. Louis Creek, the hydrograph shown on Chart CS-SLC-26 was synthesized, through the steps shown on Chart CS-SLC-27, using total daily melt volumes as computed by Light's equation, with K = 0.926. A surprising degree of agreement with the observed hydrograph was attained.

1. Forecasting rates of run-off from snowmelt. This led to the attempt at forecasting, through Light's equation, of the 1949 hydrograph of St. Louis Creek. The results are shown on Chart CS-SLC-34. The basin coefficient, K = 0.926 and Charts CS-SLC-24, -10, and -25, as determined for the 1948 season were used with the total daily melt volumes as computed by Light's equation for the 1949 season.

Because of fragmentary data for some of the instruments at the wind tower, it has been possible to forecast snowmelt run-off only for the days shown on Chart CS-SLC-34. Gaps in the forecasted hydrographs are the result of missing wind records. Six-hour average dew point temperatures used in Light's equation for the calculation of snowmelt and evaporation for the period June 15 to 20, inclusive, 1949, were derived through correlation from the Fraser Headquarters hygrothermograph record.

Because of the gaps, the forecasted hydrographs are shown in three sections. The second and third sections of the forecasted hydrographs were started at a point having the same displacement from the observed hydrograph as the end of the preceding forecasted section. For the periods shown on Chart CS-SLC-34, there is surprising agreement between the observed hydrograph and the hydrographs forecasted by either Light's equation or the multiple correlation equation "e".

According to Chart CS-SLC-34, on June 10 the actual run-off at the peak was 140 cfs while the flow forecasted by Light's equation was 160 cfs. In terms of gage heights, 140 cfs corresponds to 1.88 feet and 160 cfs to 1.95 feet, so that the difference is only 0.07 of a foot or 0.8 of an inch. Similarly for the trough of the same day's melt, the actual run-off was 120 cfs while the forecasted value was 126 cfs. Again in terms of gage heights, this represents an error of 0.02 of a foot or a little over 0.2 of an inch.

On Chart CS-SLC-34, on June 17, 1949 the actual run-off at the peak was 265 cfs. The peak for that day forecasted by Light's equation was 274 cfs. 265 cfs corresponds to 2.30 feet gage height at the St. Louis Creek gaging station; 274 cfs corresponds to 2.33 feet gage height. The difference: 0.03 foot amounts to about 0.3 inch. The trough of the actual hydrograph on June 18, 1949, was 216 cfs; that trough computed by Light's equation was 204 cfs. At the St. Louis Creek gaging station 216 cfs corresponds to 2.14 feet gage height, 204 cfs corresponds to 2.10 feet gage height. The difference 0.04 foot amounts to about 0.4 inch.

In both these instances the difference between the forecasted and actual run-offs is very small and is well within practical operational flow-routing limits.

A comparison of the 1949 forecasted total daily contributions to run-off of St. Louis Creek as computed both by Light's equation and by multiple-correlation equation "e" is shown in Table CS-SLC-T33. The actual 1949 snowmelt season daily contributions to run-off are being computed and will be presented in the report for the 1949 snowmelt season.

This progress report presents the computations and analyses completed to date and does not by any means exhaust the analytical possibilities. Investigations are being continued and the results will be presented in forthcoming reports. Charts and tables listed in the appendices, but not included in this report, are available on request.

G. Acknowledgments

General supervision over this cooperative program is being exercised by J. R. Riter, Chief, Hydrology Division, Bureau of Reclamation, and W. G. McGinnies, Director, Rocky Mountain Forest and Range Experiment Station, Forest Service.

For the Bureau of Reclamation, W. U. Garstka has been responsible throughout for the technical aspects of the program; for the Forest Service, Dr. H. G. Wilm was responsible until January 1948, at which time he was succeeded by Dr. Dudley H. Love. Bertram C. Goodell, of the Forest Service has been in immediate charge of installation and operation of the field instrumentations within the Fraser Experimental Forest. The St. Louis Creek stream gaging station is maintained jointly by the Office of the Colorado State Engineer and the Geological Survey, United States Department of the Interior. The Fraser, Colorado, standard precipitation gage and the Redcliff, Colorado, hygrothermograph station are operated by the Weather Bureau, United States Department of Commerce. The assistance of the Denver Finance Division, Bureau of Reclamation, in the machine processing of multiple correlation computations is acknowledged.

This progress report incorporates work performed at various times by the following, arranged alphabetically:

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10. Wilm, H. G., and Dunford, E. G., Effect of timber cutting on water available for streamflow from a lodgepole pine forest, Technical Bulletin No. 968, U. S. Dept. of Agriculture, Nov. 1948.

11. Wilson, W. T., An outline of the thermodynamics of snowmelt, Trans. Amer. Geophys, Union, pp. 182-194, 1941

SUPPLEMENTAL MATERIAL

Space limitations in this progress report did not permit the inclusion of all basic data tabulations and other material listed in the Appendix table of contents. Only sheets for which a page number is given are included in this report.

All materials listed on the Appendix table of contents are available upon request. Inquiries should be addressed either to Chief, Hydrology Division, Branch of Project Planning, Bureau of Reclamation, United States Department of the Interior, Denver Federal Center, Denver, Colorado; or to Director, Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Fort Collins, Colorado.

APPENDIX I

BASIC DATA

Charts		Page
CS-SLC-35	Map of Fraser Experimental Forest	20
CS-SLC-32	Area--Elevation Relationship, St. Louis Creek	21

Tables

1. Temperature--hourly values 22

One tabulation sheet is included in this report. Similar tabulations are available at the following stations for the periods specified:

Fraser Headquarters Station	April 5, 1947-July 31, 1947 April 2, 1948-July 11, 1948
East St. Louis Station	April 28, 1947-July 23, 1947
West St. Louis Station	March 20, 1948-July 18, 1948
Shadow Mountain near Grand Lake, Colorado	March 31, 1948-July 31, 1948
Redcliff, Colorado	April 1, 1948-July 31, 1948

Tables Page

2. Relative Humidity--hourly values 23

One tabulation sheet is included in this report. Similar tabulations are available for the same stations and periods as listed in 1 above.

3. Dew point temperature--hourly values. 24

A sample tabulation of hourly values of dew point temperature computed from humidity and temperature records is included. Similar tabulations are available for Fraser Headquarters Station and West St. Louis Station for the period May 14, 1948 to June 5, 1948, inclusive.

4. Wind--hourly values 25

A sample sheet of hourly values of wind at the West St. Louis Station is included in this report. Similar tabulations are available for the period March 24, 1948 to July 18, 1948, at the open site and April 9, 1948 to June 14, 1948 at the Forest site, except April 19 to 26, inclusive, and July 7-12, inclusive.

5. Wind--daily totals 26

A sample tabulation of daily totals of wind at the West St. Louis Station is included. Similar tabulations are available for the same period as in 4. above.

6. Rate of Run-off--hourly values 27

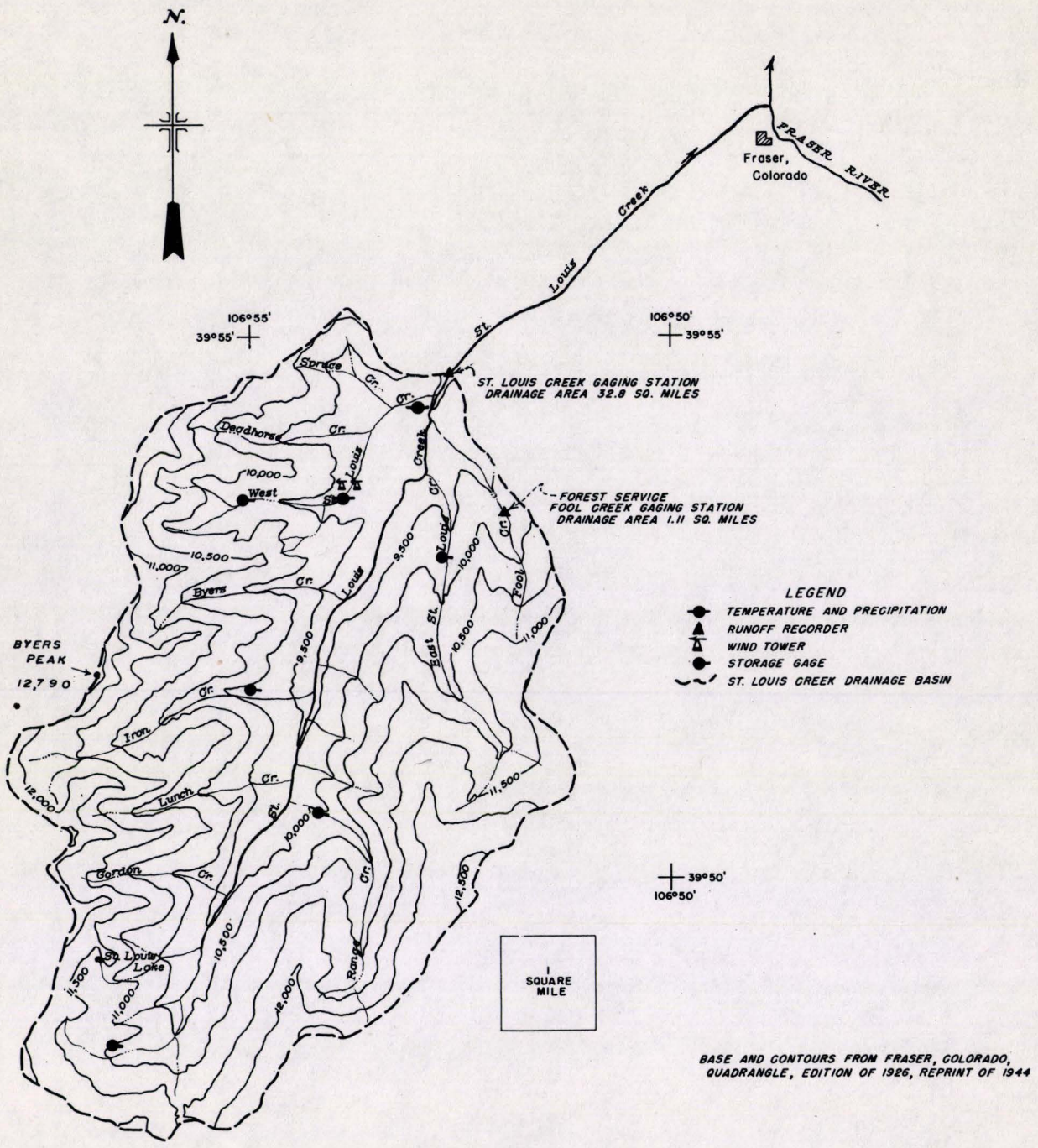
A tabulation of hourly values of rate of run-off in cubic feet per second of St. Louis Creek near Fraser, Colorado, for the period May 13, 1948 to June 5, 1948, inclusive, is included.

COOPERATIVE SNOW INVESTIGATIONS

UNITED STATES
DEPARTMENT OF AGRICULTURE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING, HYDROLOGY DIVISION

FRASER EXPERIMENTAL FOREST, COLORADO



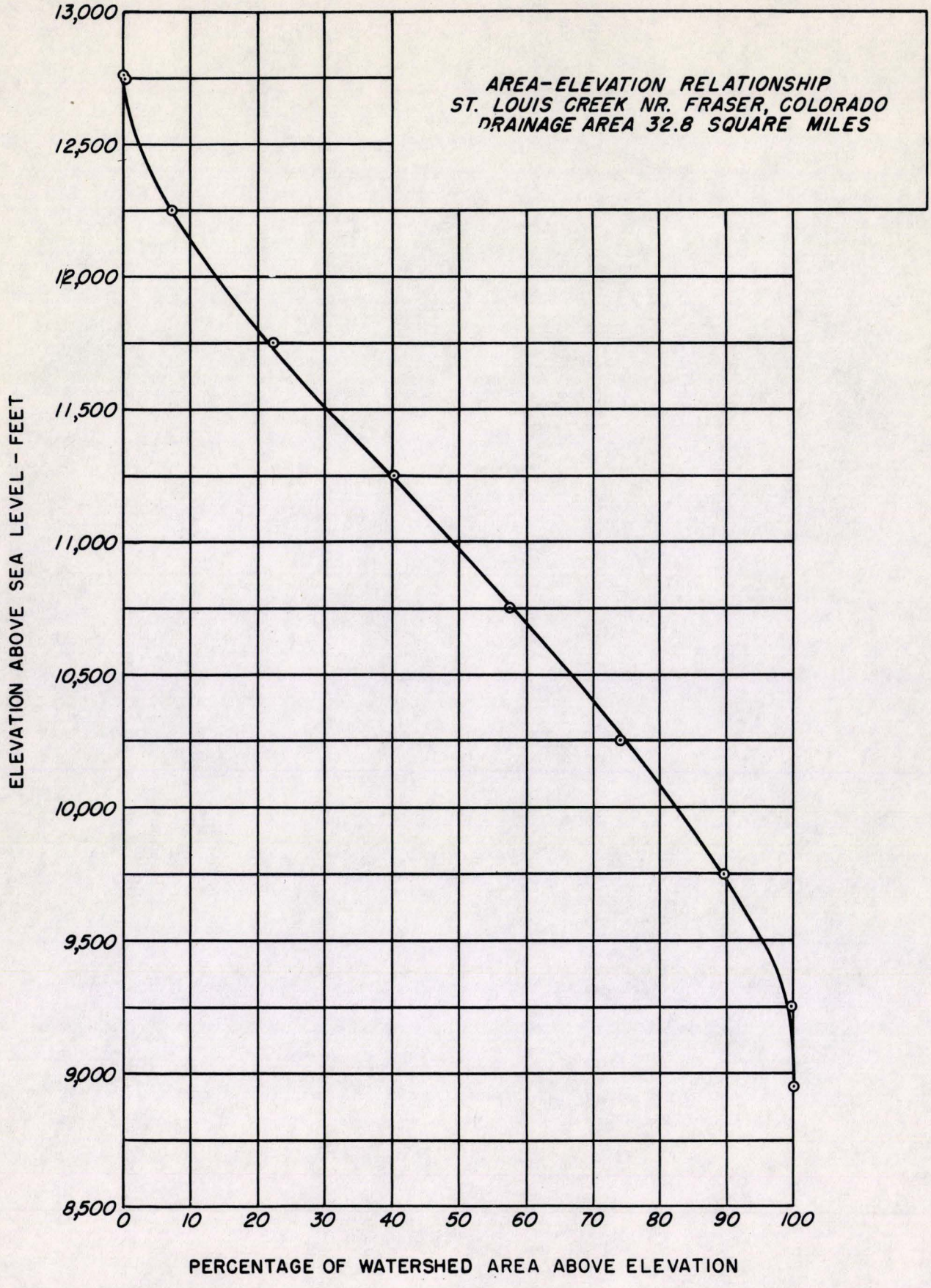
BASE AND CONTOURS FROM FRASER, COLORADO, QUADRANGLE, EDITION OF 1926, REPRINT OF 1944

Scale: 1 0 1 MILES

CONTOUR INTERVAL 500 FEET

J.M.L.-D.K.B.
8-2-49

CS-SLC-35



J.M.L.
5-25-49

CS-SLC-32

MAY 1948

UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

DATA SHEET; HOURLY RECORDS

Station HEADQUARTERS STATION
FRASER EXPERIMENTAL FOREST

Data AIR TEMPERATURE °F.
FROM HYGROTHERMOGRAPH TRACE

DATE	A.M.												P.M.												SUM	MEAN	Instantaneous °F	
	1	2	3	4	5	6	7	8	9	10	11	NOON	1	2	3	4	5	6	7	8	9	10	11	Mid't			Mean Days above 32°F	Mean Max Min
1	25	24	23	23	27	27	29	34	39	41	44	45	41	45	46	43	40	39	35	32	28	26	23	21	800	33.3	4.5	33.5
2	19	19	19	19	20	22	25	32	37	39	39	41	39	39	37	37	36	35	34	32	31	29	28	28	736	30.7	1.9	30.0
3	28	28	29	28	28	27	28	30	32							43	42	41	34	28	26	23	21	19				
4	18	17	18	19	18	29	40	41	45	46	46	45	45	43	45	44	44	39	38	35	33	32	29	28	837	34.9	6.2	31.5
5	27	27	26	26	25	25	26	28	32	35	37	39	39	40	39	37	37	35	32	29	25	23	19	17	725	30.2	2.1	28.5
6	15	14	12	11	11	17	28	37	41	46	50	52	53	55	55	56	52	50	44	36	31	27	26	25	844	35.2	8.8	33.5
7	25	25	24	23	23	27	41	47	57	58	60	58	61	61	60	58	55	49	46	41	35	42	37	32	1045	43.5	13.4	42.0
8	29	28	31	27	25	28	43	48	51	53	54	53	54	55	51	46	45	44	41	36	33	29	26	25	955	39.8	9.5	40.0
9	22	22	22	21	21	22	25	26	27	29	31	29	31	29	28	29	30	29	29	25	21	18	16	13	595	24.8	0	22.0
10	13	12	11	9	9	12	24	31	37																			
11								40	40	39	33	33	33	31	30	28	27	27	27	26	25	22	19	19				
12	17	17	22	28	33	37	40	36	32	33	36	38	37	38	35	29	26	24	21	20	20	19	18	18	674	28.1	1.8	28.5
13	18	18	24	36	44	51	54	56	56	58	59	60	56	53	47	38	32	29	26	26	25	24	34	39	963	40.1	10.8	39.0
14	37	40	45	53	56	57	58	59	61	61	62	61	58	57	53	44	38	34	32	29	28	27	26	25	1101	45.9	14.9	43.5
15	25	24	31	43	49	53	57	58	60	60	61	61	59	57	54	43	36	31	28	27	26	25	24	24	1016	42.3	12.6	42.5
16	23	22	27	41	49	55	60	63	64	65	65	65	66	62	59	45	38	35	32	30	29	28	28	27	1078	44.9	14.7	44.0
17	27	27	30	44	53	60	67																					
18														52	57	60	55	51	44	39	37	35	35	33				
19	33	33	30	30	34	51	57	59	55	56	61	59	61	63	63	58	54	50	43	40	40	40	42	42	1154	48.1	16.3	46.5
20	36	32	30	28	30	43	54	60	63	66	68	69	64	64	60	57	57	52	44	39	43	42	36	31	1168	48.7	17.0	48.5
21	30	31	28	27	30	37	49	57	63	66	68	68	67	68	65	64	60	54	49	45	37	35	33	31	1162	48.4	17.0	47.5
22	28	27	26	25	27	40	50	55	60	64	67	66	67	68	67	66	62	55	42	35	31	29	27	26	1110	46.3	16.0	47.5
23	25	25	24	24	26	36	46	53	57	61	64	64	63	61	60	59	58	55	46	38	35	33	31	29	1073	44.7	14.4	44.0
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30	28	27	26	26	25	28	40	46	54	60	66	68	69	69	68	66	65	62	58	52	46	42	36	34	1161	48.4	17.7	47.0
31	33	31	33	34	34	34	38	46	54	67	69	69	64	64	64	60	61	58	54	48	42	40	47	36	1146	47.8	17.2	50.0
Sums																												
Means																												

HD-41

Checked by JLY-PP 12-8-48 TABULATED BY PP-JML DATE 12-1-48

MAY 1948

UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

DATA SHEET; HOURLY RECORDS

HEADQUARTERS STATION
FRASER EXPERIMENTAL FOREST

Station _____ *Data* _____ RELATIVE HUMIDITY % FROM HYGROTHERMOGRAPH TRACE

DATE	A.M.												P.M.												SUM	MEAN	Instantaneous °F	
	1	2	3	4	5	6	7	8	9	10	11	NOON	1	2	3	4	5	6	7	8	9	10	11	Mid't				
1	85	92	91	73	78	83	62	49	42	42	38	41	39	35	33	35	38	47	66	88	95	99	100	100				
2	100	98	100	100	100	100	69	36	36	35	37	38	37	36	60	80	64	69	70	79	88	93	92	91				
3	98	81	83	78	71	63	59			37	35	32	30	30	29	29	31	36	60	75	79	83	89	93				
4	97	96	94	86	67	37	36	42	38	35	38	39	37	42	41	40	45	61	68	98	100	95	86	93				
5	88	89	89	91	88	76	65	53	45	37	36	36	32	32	33	33	32	34	40	52	68	74	84	92				
6	94	97	98	97	97	83	41	36	33	27	22	22	22	22	22	24	25	28	53	69	85	92	93	95				
7	94	93	95	96	96	68	40	31	27	24	24	23	21	19	20	23	30	42	48	61	68	44	70	84				
8	91	76	72	86	93	59	33	29	25	23	23	24	23	25	31	35	36	38	44	56	64	83	85	90				
9	98	97	97	99	98	85	69	78	83	80	75	86	86	90	94	85	86	85	93	95	96	98	97	100				
10	100	99	98	97	99	100	82		45	48	58	47	48	53	56	70	90	96	98	100	100	95	96	95				
11	94	99	100	96	79	82	68	57	52	50	82	80	79	88	92	95	97	97	97	95	94	91	89	93				
12	89	94	95	88	70	67	58	53	78	83	72	58	61	59	61	81	93	94	97	98	97	97	98	97				
13	97	97	98	53	35	26	24	21	19	20	19	18	19	23	30	58	77	84	90	93	93	95	48	36				
14	40	37	29	22	21	22	22	21	21	21	19	19	20	22	24	42	65	75	86	95	96	92	95	95	1101	45.9		
15	93	88	86	33	30	29	22	22	20	19	18	17	17	18	20	41	63	76	86	90	89	92	96	96	1261	52.5		
16	96	99	91	41	37	29	23	18	17	16	16	16	15	20	31	53	75	89	96	98	99	99	98	97	1369	57.0		
17	97	98	98	55	46	33	23	20								17	18	30	50	66	75	81	87	86				
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24	100	100	100	99	98	97	57		36	36	34	33	35	36	38	41	42	45	52	69	82	90	94	97	1558	64.9		
25	96	96	96	95	96	96	80	57	45	40	39	38	38	42	46	47	46	59	62	74	85	86	93	96	1648	68.7		
26	97	96	96	96	96	96	62	57	40	36	32	35	33	38	33	45	50	65	73	82	84	92	95	97	1626	67.8		
27	98	97	98	97	96	98	76	55	44	42	38	46	42	38	36	42	46	49	60	66	75	82	85	94	1600	66.7		
28	94	94	90	92	96	98	96	79	64	58	38	37	34	64	90	69	59	73	84	91	95	96	98	98	1887	78.6		
29	98	98	98	97	97	97	84	52	42	30	29	24	22	22	20	22	24	26	34	55	68	80	87	90	1396	58.2		
30	93	92	94	96	96	98	60	52	36	29	21	19	19	25	26	32	36	40	42	60	73	81	92	96	1408	58.7		
31	98	98	100	97	98	98	98	70	46	23	22	23	26	24	30	36	34	40	48	64	76	78	84	87	1498	62.4		
Sums																												
Means																												

HD-41

After 9 a.m. 5-24-49 Copied from Forest Service Tabulation

TABULATED BY _____ DATE _____

MAY 1948

UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

DATA SHEET; HOURLY RECORDS

HEADQUARTERS STATION,

Station FRASER EXPERIMENTAL FOREST

Data DEW POINT TEMPERATURES

DATE	A.M.												P.M.												SUM	MEAN	Instantaneous °F	
	1	2	3	4	5	6	7	8	9	10	11	NOON	1	2	3	4	5	6	7	8	9	10	11	Mid't				
1																												
2																												
3																												
4																												
5																												
6																												
7																												
8																												
9																												
10																												
11																												
12																												
13																												
14	17	18	17	17	18	20	21	20	22	22	21	20	19	20	19	24	28	28	29	28	27	25	25	24	529	22.0		
15	23	21	28	18	20	23	20	21	20	19	19	18	16	16	16	22	25	25	25	25	24	24	23	23	514	21.4		
16	22	22	25	21	25	24	23	20	20	19	19	19	19	22	29	29	31	32	31	30	29	28	28	26	593	24.7		
17	26	27	30	29	33	31	28																					
18														19	34	34	34	36	36	34	34	32	33	32				
19	33	32	29	30	34	30	31	31	30	31	33	33	31	32	32	30	29	33	32	31	31	31	31	30	750	31.2		
20	30	30	29	27	30	28	29	25	23	22	24	27	30	30	28	30	32	33	31	32	30	29	31	29	689	28.7		
21	29	29	28	27	30	34	30	29	29	25	26	26	25	27	25	24	32	35	35	33	29	31	31	29	698	29.1		
22	27	27	26	25	27	26	29	29	29	21	22	19	18	17	15	14	14	17	25	26	24	25	24	23	549	22.9		
23	23	24	23	22	22	23	23	25	26	26	26	29	30	32	36	36	35	36	37	34	33	32	31	29	693	28.9		
24	28	27	27	28	29	33	32	*32	32	33	33	33	31	30	31	32	31	31	31	35	35	31	30	31	746	31.1		
25	30	30	30	30	30	34	34	32	30	29	31	32	32	32	32	31	30	34	34	32	30	29	26	26	740	30.8		
26	25	24	24	23	23	31	27	31	28	28	27	27	28	29	29	31	33	38	36	35	34	33	31	29	704	29.3		
27	29	27	28	26	26	34	37	34	33	30	31	32	31	32	30	31	31	31	34	34	35	35	36	37	764	31.8		
28	37	36	32	30	32	34	39	40	38	39	31	32	22	35	42	38	36	39	40	36	33	31	31	29	832	34.7		
29	29	29	29	27	29	31	40	33	32	26	26	25	22	22	23	24	23	23	27	31	30	30	29	28	668	27.8		
30	26	25	25	25	24	28	28	30	28	28	26	25	26	32	32	35	37	37	35	39	38	37	34	33	733	30.5		
31	33	31	33	33	34	34	37	37	34	28	29	30	29	27	32	33	32	34	35	36	35	34	42	32	794	33.1		
Sums																												
Means																												

HD-41

* Estimated

Checked by PP 3-14-49 TABULATED BY JLY DATE 2-21-49

RI - RM
STREAMFLOW
Forests
Coop. Snow Study

Form RI-15
New 12/13/48
BCG

WIND MOVEMENT, HOURLY AND DAILY

West St. Louis Climatic Station, Fraser Experimental Forest

Date 5-22-48	Hour	Miles of Wind												Remarks
		Open Site						Forest Site						
		Low anem.		Mid. anem.		High anem.		Low anem.		Mid. anem.		High anem.		
		Increment	Accumulation	Increment	Accumulation	Increment	Accumulation	Increment	Accumulation	Increment	Accumulation	Increment	Accumulation	
	1a	2	5058.2	4	7374.9	6	7685.5	1	1264.6	0	930.1			
	2	2	5060.2	4	7378.9	4	7689.5	0	1264.6	0	930.1			
	3	2	5062.2	5	7383.9	6	7695.5	1	1265.6	1	931.1			
	4	2	5064.2	5	7388.9	5	7700.5	1	1266.6	0	931.1			
	5	2	5066.2	4	7392.9	4	7704.5	0	1266.6	0	931.1			
	6	1	5067.2	1	7393.9	1	7705.5	1	1267.6	0	931.1			
	7	0	5067.2	1	7394.9	1	7706.5	0	1267.6	0	931.1			
	8	2	5069.2	4	7398.9	4	7710.5	1	1268.6	1	932.1			
	9	3	5072.2	5	7403.9	6	7716.5	2	1270.6	1	933.1			
	10	4	5076.2	6	7409.9	6	7722.5	3	1273.6	1	934.1			
	11	4	5080.2	6	7415.9	7	7729.5	2	1275.6	2	936.1			
	12	3	5083.2	6	7421.9	7	7736.5	3	1278.6	1	937.1			
	1p	4	5087.2	6	7427.9	7	7743.5	2	1280.6	2	939.1			
	2	4	5091.2	7	7434.9	8	7751.5	3	1283.6	1	940.1			
	3	4	5095.2	6	7440.9	7	7758.5	3	1286.6	2	942.1			
	4	2	5097.2	7	7447.9	7	7765.5	2	1288.6	1	943.1			
	5	2	5099.2	3	7450.9	4	7769.5	2	1290.6	1	944.1			
	6	1	5100.2	3	7453.9	2	7771.5	1	1291.6	0	944.1			
	7	3	5103.2	6	7459.9	7	7778.5	1	1292.6	0	944.1			
	8	3	5106.2	7	7466.9	9	7787.5	1	1293.6	2	946.1			
	9	3	5109.2	6	7472.9	6	7793.5	2	1295.6	1	947.1			
	10	4	5113.2	6	7478.9	6	7799.5	2	1297.6	1	948.1			
	11	3	5116.2	7	7485.9	7	7806.5	1	1298.6	1	949.1			
	12	2	5118.2	4	7489.9	5	7811.5	1	1299.6	1	950.1			
Day Total		62		119		132		36		20				
Odometer Reading														

Compiled by JRI Date 12-28-48 Checked by JRI Date 12-28-48

WIND MOVEMENT, DAILY TOTAL

WEST ST. LOUIS STATION
FRASER EXPERIMENTAL FOREST, COLORADO

	MILES OF WIND				
	OPEN SITE			FOREST SITE	
Date May 1948	1.4' Above Snow Surface	23.1' Above Ground	47.4' Above Ground	1.4' Above Snow Surface	24.9' Above Ground
1	58	87	91	29	20
2	47	73	82	26	18
3	52	79	88	32	22
4	63	100	109	43	30
5	61	95	107	39	28
6	65	107	112	32	24
7	65	104	115	36	27
8	72	113	128	43	28
9	35	55	60	9	7
10	40	73	76	17	10
11	11	33	36	6	6
12	42	74	85	20	16
13	64	104	108	31	25
14	81	125	137	47	33
15	71	110	121	37	28
16	60	95	104	27	20
17	60	101	111	30	21
18	52	102	110	29	17
19	56	107	117	37	24
20	61	119	132	33	21
21	71	127	135	37	23
22	62	119	132	36	20
23	55	101	110	24	15
24	44	84	91	22	10
25	51	89	99	30	18
26	40	75	87	16	7
27	53	94	102	27	14
28	37	74	82	19	10
29	51	97	112	28	16
30	61	110	125	35	19
31	62	111	124	34	17

ST. LOUIS CREEK NEAR FRASER, COLORADO
DRAINAGE AREA 32.8 SQUARE MILES

RATE OF RUNOFF--CUBIC FEET PER SECOND*
expressed to nearest one-half c.f.s.

Date 1948	A.M. 1	2	3	4	5	6	7	8	9	10	11	Noon	P.M. 1	2	3	4	5	6	7	8	9	10	11	Mid't
May 12																								22
13	21	18	15	16.5	17	19.5	22	24.5	30	25	24.5	24.5	24	23	24.5	26	27	29	30	31	31	31	31	30
14	30	29	28	28	27	27	27	26	25	25	26	27	30	33	38	42.5	46	51	52	52	52	51	51	48
15	47	46	45	44	42.5	41	39	38	37	36	36	37	39	42.5	46	51	56	62	65	66.5	66.5	65	62	61
16	59	58	55	54	49	48	48	52	48	46	46	46	49	52	59	65	72.5	77	79	80	80	79	77	74
17	74	72.5	69.5	66.5	65	63.5	59	59	58	58	58	62	65	72.5	80	87	98	103.5	105	103.5	102	100	98	94
18	91	89	87	84	82	80	77	75.5	74	74	72.5	72.5	74	77	80	85.5	91	98	100	102	100	100	100	98
19	96	94	92	91	89	89	85.5	85.5	85.5	85.5	85.5	89	91	98	103.5	107	117	122	126	126	124	124	120	120
20	117	111	109	107	103.5	100	100	100	98	98	96	98	100	107	117	131	142.5	155	152.5	152.5	147.5	142.5	140	135
21	131	128	126	124	122	120	120	117	115	113	113	113	117	120	131	150	155	162.5	165	165	165	162.5	160	155
22	152.5	147.5	142.5	140.	135	131	131	128	126	124	124	124	126	131	142.5	160	170	180	180	177.5	175	170	167.5	167.5
23	165	160	155	147.5	142.5	140	135	131	131	128	128	128	131	135	142.5	152.5	157.5	162.5	165	167.5	165	162.5	160	155
24	152.5	150	147.5	142.5	140	135	135	131	131	131	131	128	131	133	135	137.5	140	142.5	142.5	142.5	142.5	142.5	140	135
25	133	131	131	131	128	128	128	126	126	126	126	126	126	128	135	147.5	160	165	167.5	165.	162.5	157.5	155	152.5
26	150	145	142.5	140	135	131	131	131	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
27	126	124	124	124	124	124	120	120	117	117	117	117	117	120	124	128	137.5	147.5	152.5	155	152.5	150	145	142.5
28	142.5	140	140	137.5	135	133	131	131	131	131	128	128	131	133	142.5	155	165	165	165	165.	162.5	157.5	155	152.5
29	147.5	142.5	142.5	140	137.5	135	131	131	131	131	131	131	128	128	131	131	133	140	140	140	140	140	137.5	137.5
30	135	135	133	133	131	131	128	128	128	128	128	128	128	131	137.5	152.5	165	167.5	170	172.5	172.5	172.5	172.5	172.5
31	167.5	165	162.5	160	155	155	152.5	147.5	142.5	142.5	140	140	150	160	167.5	175	177.5	180	180	180	180	180	180	177.5
June 1	175	172.5	170	170	167.5	165	162.5	157.5	152.5	150	147.5	150	155	165	170	177.5	180	185	191	191	191	191	185	185
2	182.5	180	177.5	177.5	175	172.5	170	167.5	167.5	165	165.	167.5	167.5	180	191	206	221	239	239	239	236	233	230	227
3	221	215	209	203	197	191	182.5	180	175	172.5	172.5	175	180	191	212	230	239	242	242	239	239	236	230	224
4	221	215	206	203	197	191	188	182.5	180	177.5	177.5	175	177.5	185	200	218	230	233	233	233	230	224	221	215
5	209	203	197	191	188	185	180	177.5	175	172.5	172.5	170	170	180	194	209	221	224	230	227	224	221	215	209
6	206	200	194	191	185	180	180	177.5	175.	172.5	170	170	175											

* Derived from original recorder chart available at Denver, Colorado, District Office, Geological Survey, Department of the Interior.

APPENDIX II

SEASONAL STORAGE GAGES

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Seasonal Storage Precipitation Gages

Fraser Experimental Forest
Cooperative Snow Investigations
Bureau of Reclamation - Forest Service

CS-T4-A

Gage Location	Approximate Elevation	Capacity of Gage - Inches	Date of Previous Servicing	Water Equivalent Gage Increment Inches	Water Equivalent at Snow Course Avg. of 10 Samples Inches	Date of Survey
April 1, 1947						
East St. Louis	9,650	100	11-17-46	9.25	13.80	4- 1-47
Iron Creek	10,000	100	11-16-46	11.25	11.75	4- 1-47
Range Creek	10,050	100	11-16-46	9.25	14.15	4- 1-47
St. Louis Pass	10,950	200	10-25-46	21.00	23.11	4- 3-47
W. St. Louis Creek	9,550	100	11-17-46	4.80 10.40 *	28.77	4- 2-47
April 1, 1948						
East St. Louis	9,650	100	9-25-47	12.50	14.35	4- 2-48
Iron Creek	10,000	100	9-26-47	13.50	11.25	3-31-48
Range Creek	10,050	100	9-26-47	12.00	13.40	3-31-48
St. Louis Pass	10,950	200	9-26-47	10.50	18.95	4- 1-48
W. St. Louis Creek	9,550	100	9-25-47	18.00	20.25	4- 2-48
May 1, 1947						
East St. Louis	9,650	100	4- 1-47	3.50	14.72	5- 2-47
Iron Creek	10,000	100	4- 1-47	4.00	12.92	4-29-47
Range Creek	10,050	100	4- 1-47	3.50	15.42	4-29-47
St. Louis Pass	10,950	200	4- 3-47	5.80	23.32	4-30-47
W. St. Louis Creek	9,550	100	4- 2-47	4.15	23.92	4-29-47
May 1, 1948						
East St. Louis	9,650	100	4- 2-48	3.00	10.65	4-28-48
Iron Creek	10,000	100	3-31-48	4.00	6.10	5- 4-48
Range Creek	10,050	100	3-31-48	4.50	10.15	5- 4-48
St. Louis Pass	10,950	200	4- 1-48	9.00	18.55	5- 4-48
W. St. Louis Creek	9,550	100	4- 2-48	5.50	16.96	4-29-48

* Water equivalent in gage plus that on top of gage opening.

Seasonal Storage Precipitation Gages

Fraser Experimental Forest
Cooperative Snow Investigations
Bureau of Reclamation - Forest Service

1949

Gage Location	Approximate Elevation	Capacity of Gage - Inches	Gage Shielded or Unshielded	Date of Previous Servicing	Water Equivalent Gage Increment Inches	Water Equivalent at Snow Course Avg. of 10 Samples Inches	Date of Survey
April 1, 1949							
E. St. Louis Creek	9,650	100	shielded	9-22-48	11.7	14.0	4- 8-49
Iron Creek	10,000	100	shielded	10- 2-48	13.3	10.7	4-12-49
Range Creek	10,050	100	shielded	10- 1-48	10.8	11.6	4-12-49
St. Louis Pass	10,950	200	unshielded	10- 1-48	17.3	20.0	4-12-49
W. St. Louis Creek	9,550	100	shielded	9-28-48	18.1	19.1	4- 7-49
W. St. Louis Creek	9,550	100	unshielded	9-28-48	15.8	19.1	4- 7-49
May 1, 1949							
E. St. Louis Creek	9,650	100	shielded	4- 8-49	1.8	11.3	5- 2-49
Iron Creek	10,000	100	shielded	4-12-49	2.0	0.0	5- 3-49
Range Creek	10,050	100	shielded	4-12-49	1.8	8.1	5- 3-49
St. Louis Pass	10,950	200	unshielded	4-12-49	2.8	18.5	5- 3-49
W. St. Louis Creek	9,550	100	shielded	4- 7-49	2.3	14.7	4-29-49
W. St. Louis Creek	9,550	100	unshielded	4- 7-49	1.4	14.7	4-29-49

APPENDIX III

DEGREE-DAY DERIVATION

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CS-R-10	Max. Air Temp. °F vs. Degree Days above 32° F, May 1948.	
	Shadow Mountain	
CS-SM-19	Avg. of Max. ∕ Min. Temp. °F. vs. Degree Days, April, May, and June 1948.	
CS-SM-20	Avg. of Max. Air Temp. °F. vs. Degree Days, April, May, and June 1948.	
CS-SM-10	Max. Air Temp. °F vs. Degree Days above 32° F., May 1948.	
	Fraser Experimental Forest Headquarters	
CS-FH-44	Avg. of Max. ∕ Min. Temp. °F. vs. Degree Days, April, May, and June 1948.	35
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CS-FH- 6	Max. Air Temp. °F. vs. Degree Days above 32° F., April 1947.	
CS-FH-28	Avg. of Max. ∕ Min. Temp. °F. vs. Degree Days above 32° F., April 1948.	
CS-FH-29	Avg. of Max. ∕ Min. Temp. °F. vs. Degree Days above 32° F., May 1948.	33
CS-FH-30	Avg. of Max. ∕ Min. Temp. °F. vs. Degree Days above 32° F., June 1948	
CS-FH-32	Max. Air Temp. °F vs. Degree Days above 32° F., April 1948.	
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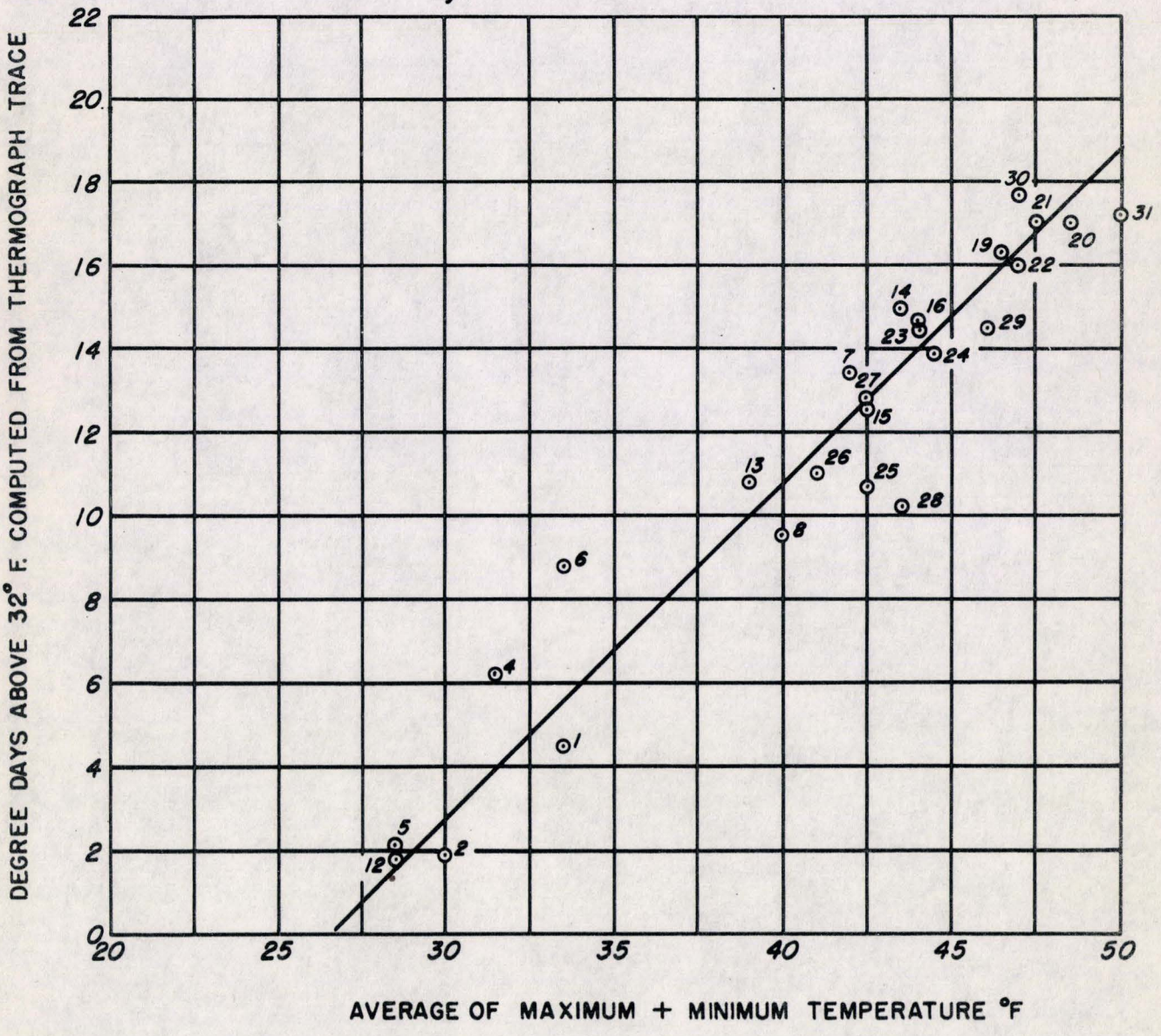
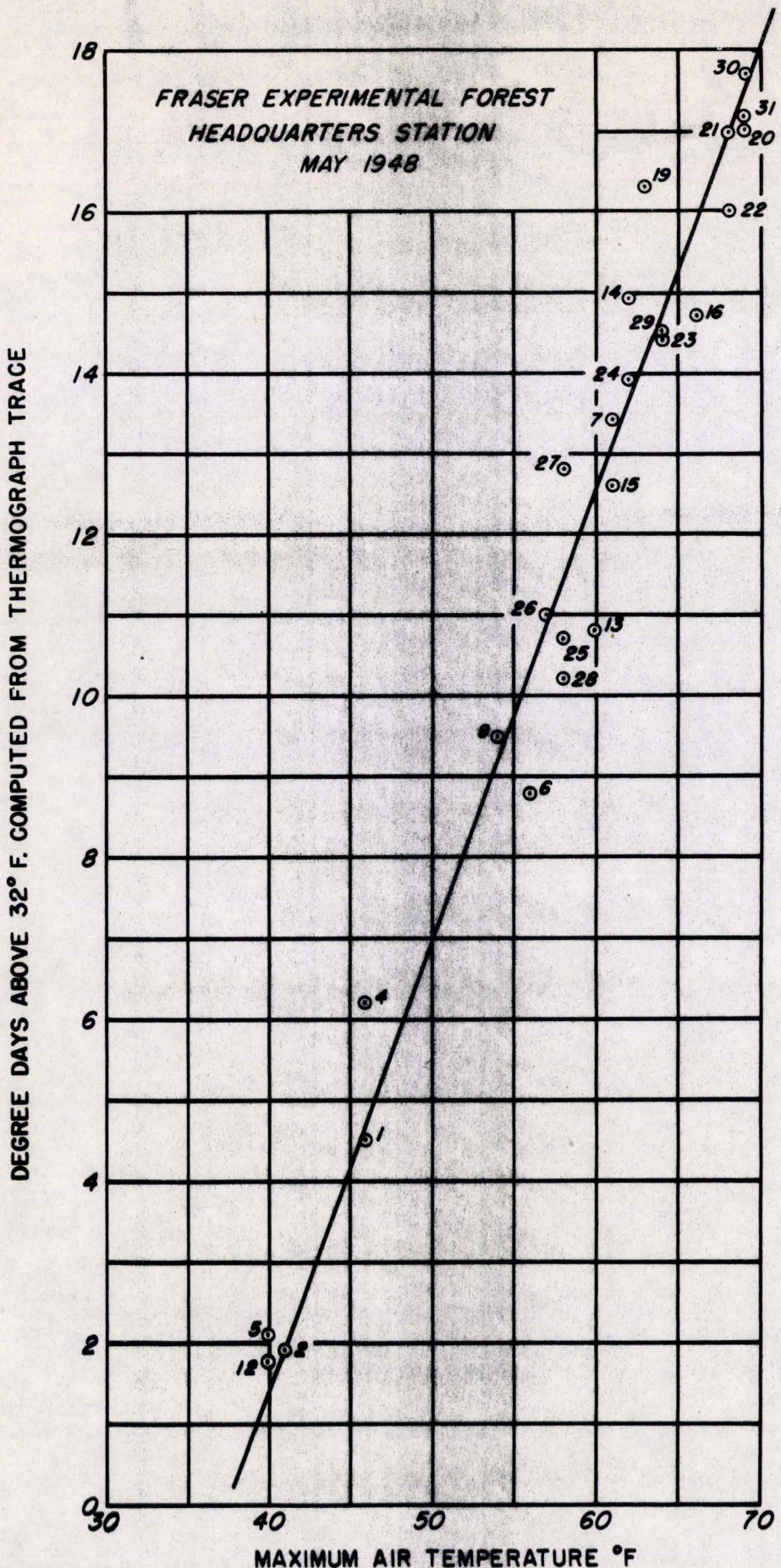
FRASER EXPERIMENTAL FOREST
HEADQUARTERS STATION
MAY 1948

$Y = 0.742X - 18.9$
$\bar{R} = 0.962$
$\bar{S}_{yx} = 1.36°$



J.M.L.
1-20-49

CS-FH-2



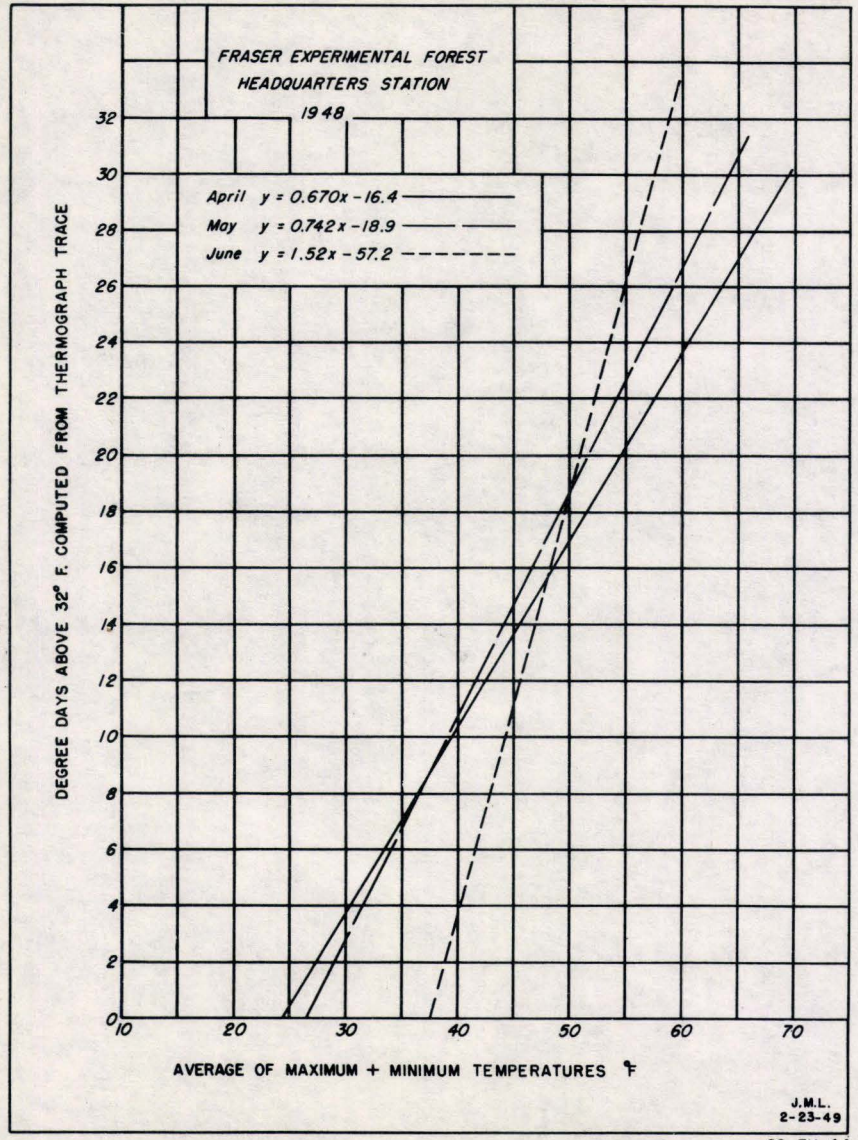
$Y = 0.532X - 19.5$

$\bar{R} = 0.982$

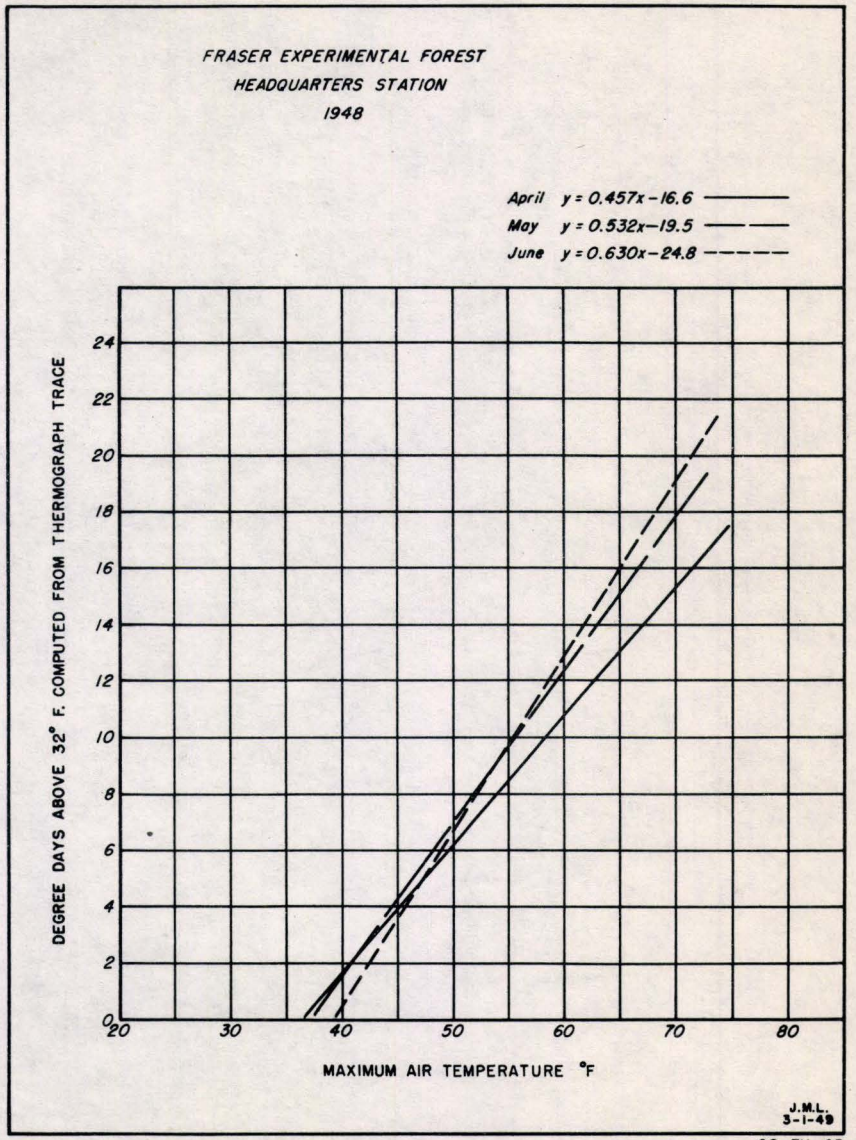
$\bar{S}_{yx} = 0.94°$

J.M.L.
1-21-49

CS-FH-33


FRASER EXPERIMENTAL FOREST
HEADQUARTERS STATION
1948
April y = 0.670x - 16.4
May y = 0.742x - 18.9
June y = 1.52x - 57.2
DEGREE DAYS ABOVE 32° F. COMPUTED FROM THERMOGRAPH TRACE
AVERAGE OF MAXIMUM + MINIMUM TEMPERATURES °F
J.M.L.
2-23-49

CS-FH-44



CS-FH-45

SUMMARY TABLE CS-T2

Degree Days as computed from hourly values of hygrothermograph records in relation to daily maximum temperature and to the average of daily maximum + minimum temperature

Comparison with maximum temperature					Comparison with average of maximum + minimum temperature	
Station	Year	Month	Relationship	Equation	Relationship	Equation
Shadow Mountain	1948	April	Curvilinear	None	Linear	None
Shadow Mountain	1948	May	Linear	y = 0.701x - 27.6	Linear	y = 0.984x - 29.9
Shadow Mountain	1948	June	Linear	y = 0.562x - 17.9	Linear	y = 1.27x - 45.7
Redcliff, Colorado	1948	April	Linear	y = 0.476x - 17.1	Linear	y = 0.755x - 19.9
Redcliff, Colorado	1948	May	Linear	y = 0.622x - 24.0	Linear	y = 1.09x - 35.0
Redcliff, Colorado	1948	June	Linear	y = 0.646x - 24.6	Linear	y = 1.44x - 53.8
Fraser Exp. Forest, Hq. Sta.	1948	April	Linear	y = 0.457x - 16.6	Linear	y = 0.670x - 16.4
Fraser Exp. Forest, Hq. Sta.	1948	May	Linear	y = 0.532x - 19.5	Linear	y = 0.742x - 18.9
Fraser Exp. Forest, Hq. Sta.	1948	June	Linear	y = 0.630x - 24.8	Linear	y = 1.52x - 57.2
Fraser Exp. Forest, Hq. Sta.	1947	May	Linear	y = 0.525x - 19.4	Linear	y = 1.01x - 31.7
Fraser Exp. Forest, Hq. Sta.	1947	June	Linear	y = 0.634x - 24.7	Linear	y = 1.13x - 35.8
Fraser Exp. Forest, Hq. Sta.	1947	July	Curvilinear	None	Linear	y = 1.78x - 72.7

TABLE CS-T1

COMPARISON OF SNOWMELT RUNOFF PER DEGREE-DAY 1948
ST. LOUIS CREEK, NEAR FRASER, COLORADO

		Degrees Fahrenheit - Headquarters Station, Fraser Experimental Forest							
Date	(A) Runoff St. Louis Creek inches	(B) Degree-days from hygro-thermograph trace	(C) Max. temp.	(D) Min. temp.	(E) Avg. of max. + min. temp.	(F) Degree-days avg. max. + min. minus 32° F	(G) Degree-days maximum minus 32° F	(H) Degree-days from chart max. + min. temp.	(I) Degree-days from chart max. temp.
May 14	0.244	14.9	62	25	43.5	11.5	30	13.5	13.6
15	0.202	12.6	61	24	42.5	10.5	29	12.8	13.0
16	0.229	14.7	66	22	44.0	12.0	34	13.9	15.8
19	0.297	16.3	63	30	46.5	14.5	31	15.9	14.1
20	0.379	17.0	69	28	48.5	16.5	37	17.5	17.4
21	0.328	17.0	68	27	47.5	15.5	36	16.7	16.8
22	0.248	16.0	68	25	47.5	15.5	36	16.7	16.8
23	0.184	14.4	64	24	44.0	12.0	32	13.9	14.6
24	0.132	13.9	62	27	44.5	12.5	30	14.3	13.6
27	0.348	12.8	58	27	42.5	10.5	26	12.8	11.4
28	0.169	10.2	58	29	43.5	11.5	26	13.5	11.4
29	0.155	14.5	64	28	46.0	14.0	32	15.5	14.6
30	0.410	17.7	69	25	47.0	15.0	37	16.3	17.4
31	0.299	17.2	69	31	50.0	18.0	37	18.7	17.4
June 1	0.500	19.6	67	29	48.0	16.0	35	15.7	17.3
2	0.343	18.2	72	31	51.5	19.5	40	21.0	20.4
3	0.286	16.8	66	28	47.0	15.0	34	14.2	16.6
4	0.164	17.1	68	26	47.0	15.0	36	14.2	17.9
5	0.202	18.9	70	26	48.0	16.0	38	15.7	19.1
TOTAL	5.119	299.8				271.0	636	292.8	299.2

SUMMARY

Inches of snowmelt runoff per degree-day	Difference from A/B	Departure from A/B percent
A/B = 0.0171		
A/F = 0.0189	0.0018	10.5%
A/G = 0.0080	-0.0091	-53.2%
A/H = 0.0175	0.0004	2.3%
A/I = 0.0171	0	0

Maximum rate of snowmelt occurred on May 27, 1948	A/B = 0.0272 inches per degree-day
Minimum rate of snowmelt occurred on June 4, 1948	A/B = 0.0096 inches per degree-day

APPENDIX IV

RATES OF SNOWMELT

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CS-SLC-28D	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1938.	
CS-SLC-28E	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1939.	
CS-SLC-28F	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1940.	
CS-SLC-28G	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1941.	
CS-SLC-28H	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1942.	
CS-SLC-28I	Hydrograph--St. Louis Creek near Fraser and Precipitation near Fraser, 1943.	
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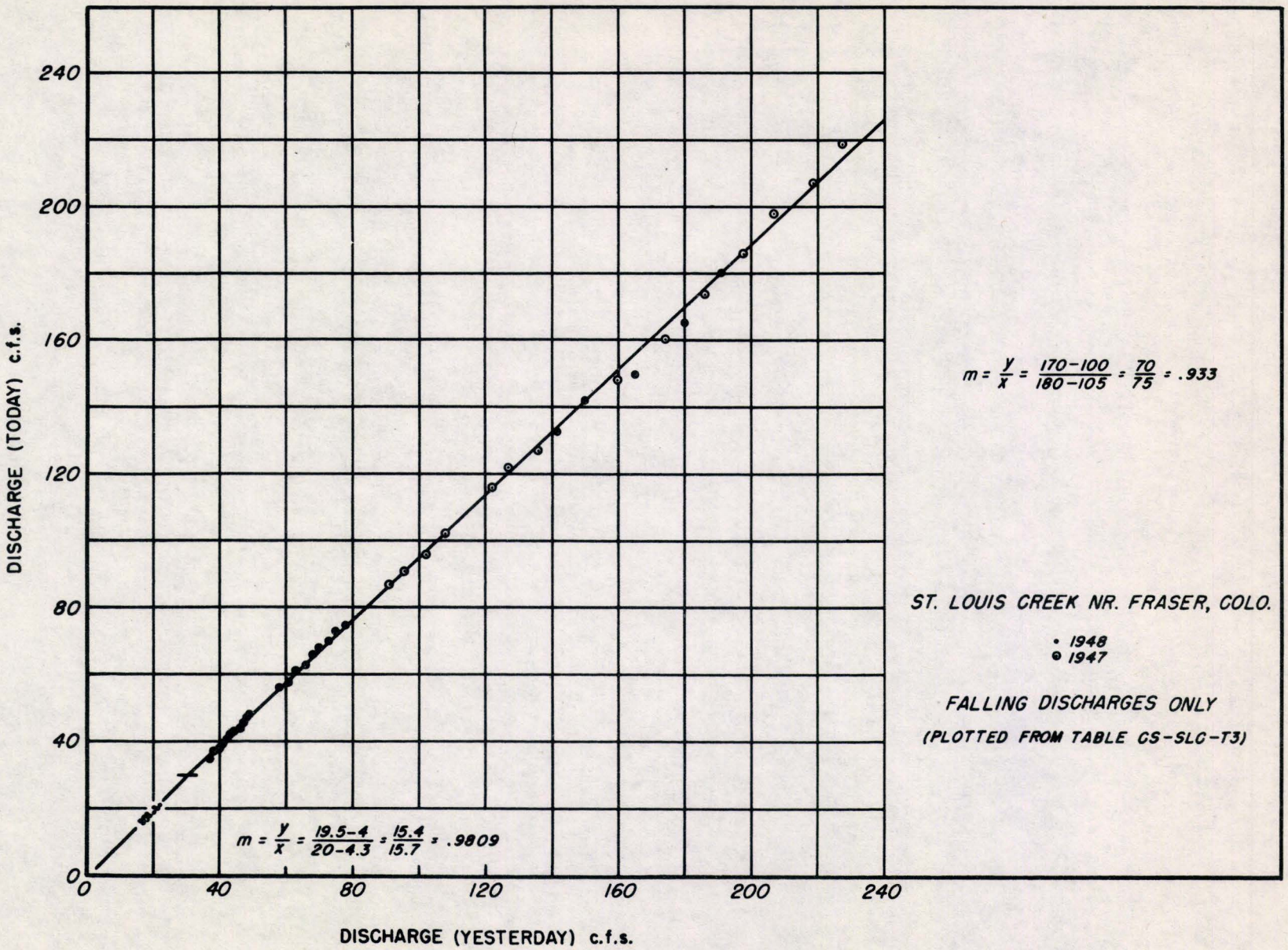
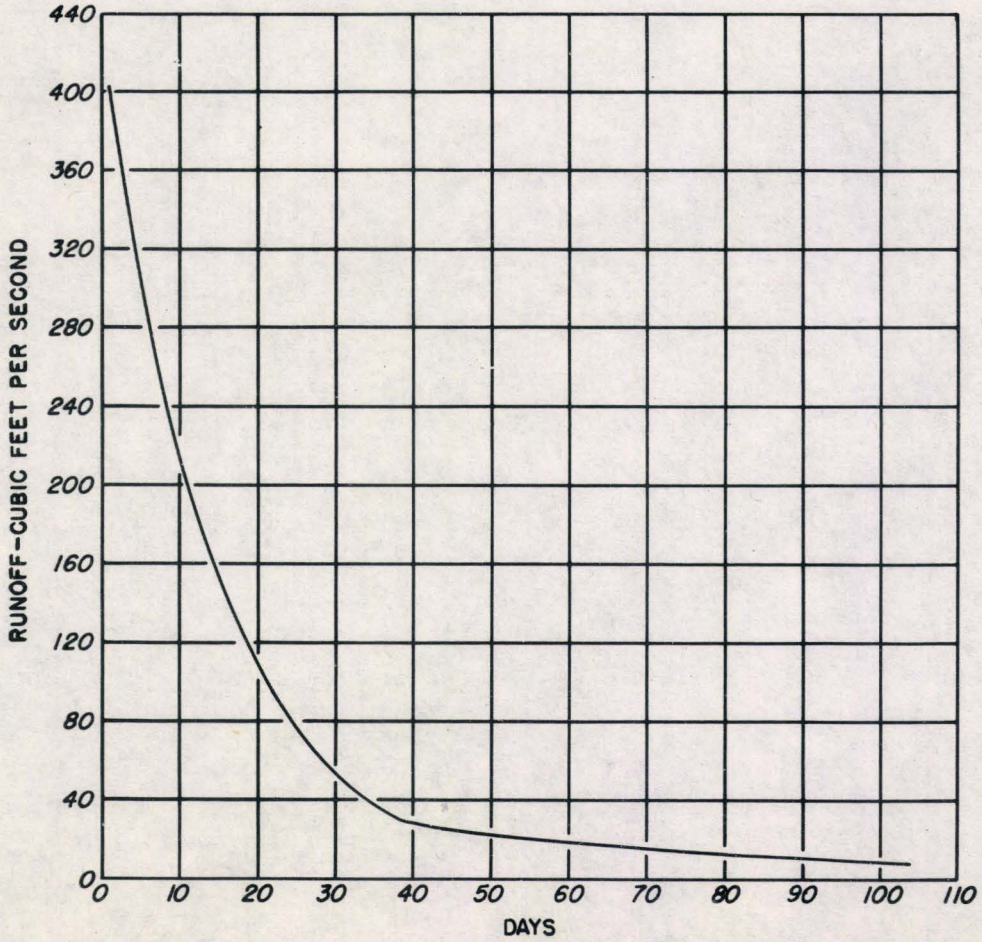


P.P.
2-3-49

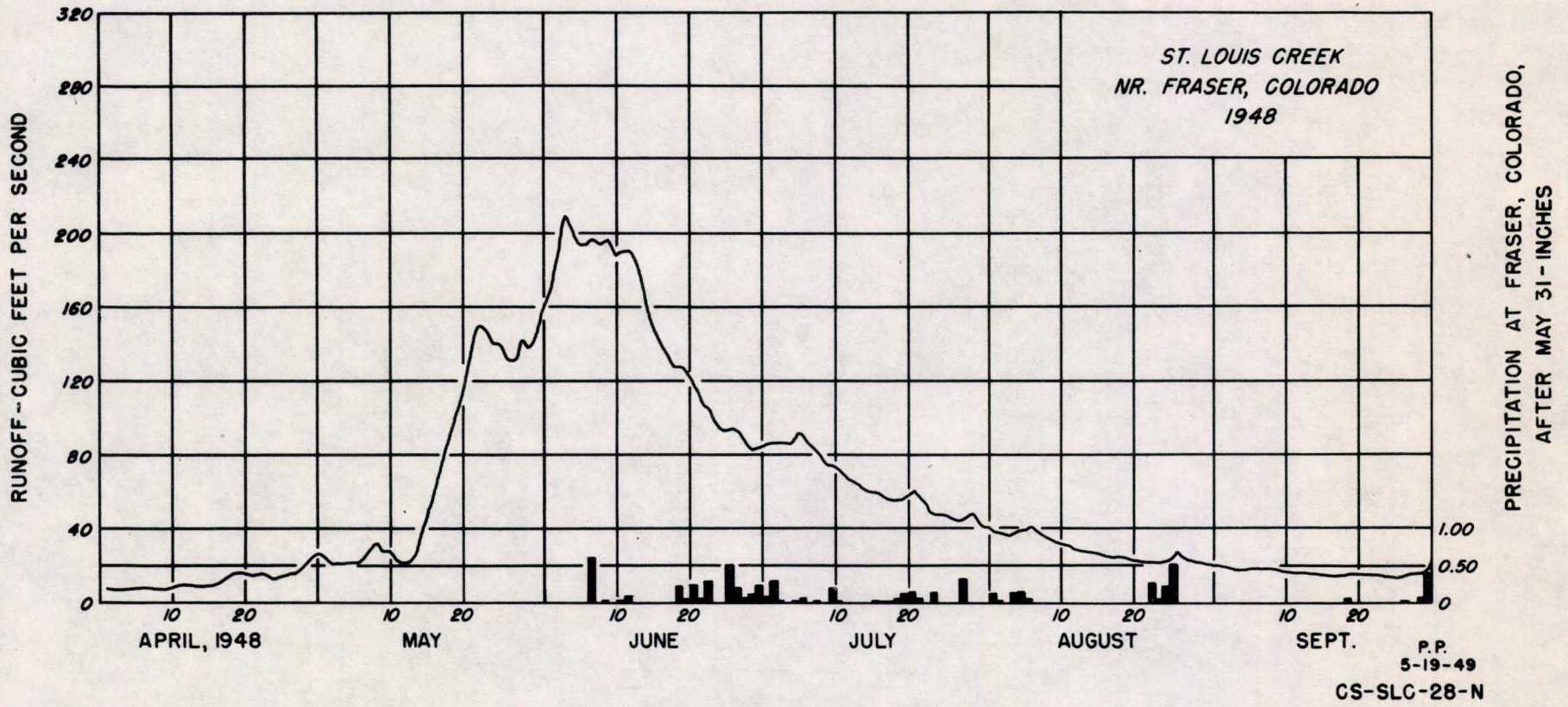
CS-SLC-6



STANDARD RECESSION CURVE
ST. LOUIS CREEK NR. FRASER, COLORADO

P. P.
5-19-49

CS-SLC-33


ST. LOUIS CREEK
NR. FRASER, COLORADO
1948
RUNOFF - CUBIC FEET PER SECOND
320
280
240
200
160
120
80
40
0
10
20
APRIL, 1948
MAY
JUNE
JULY
AUGUST
SEPT.
PRECIPITATION AT FRASER, COLORADO,
AFTER MAY 31 - INCHES
1.00
0.50
0
P.P.
5-19-49
CS-SLC-28-N

SOLAR RADIATION INCIDENT UPON HORIZONTAL SURFACE AT SHADOW MOUNTAIN STATION NEAR GRAND LAKE, COLORADO

GRAM CALORIES PER HOUR PER SQUARE CENTIMETER

MAY 13 mdnt.	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	MAY 31	JUNE 1	2	3	4	5	6	7	8	9	10	JUNE 11
780	702	810	743	642	460	590	546	788	829	811	530	452	491	445	390	608	653	626	624	770	838	822	845						

Gram-calories per square centimeter - total for the day.

WIND AT 47.4 FOOT LEVEL IN THE OPEN WEST ST. LOUIS CREEK

MILES FOR HOUR ENDING FOR HOUR ENDING

108	137	121	104	111	110	117	132	135	132	110	91	99	87	102	82	112	125	124	109	107	102	108	139						

Miles of wind - total for the day.

DEWPOINT TEMPERATURE AT HEADQUARTERS STATION

DEGREES FAHRENHEIT

22	21	25				31	29	29	23	29	31	31	29	32	35	28	31	33	32	36	28	24	27						

Average dewpoint temperature for the day.

TEMPERATURE AT HEADQUARTERS STATION

DEGREES FAHRENHEIT

14.9	12.6	14.7				16.3	17.0	17.0	16.0	14.4	13.9			12.8	10.2	14.5	17.7	17.2	19.6	18.2	16.8	17.1	18.9						

Degree days above 32° F. computed from thermograph trace.

RUNOFF RECORDED AT U.S. GEOLOGICAL SURVEY GAGING STATION AT ST. LOUIS CREEK NEAR FRASER, COLORADO

CUBIC FEET PER SECOND

13 mdnt. MAY	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 MAY	1 JUNE	2	3	4	5	6	7	8	9	10	11 JUNE
428	354	401				519	663	574	434	321	232			609	295	272	718	524	875	600	500	287	354						

Acre-feet Total contribution to runoff of the day's snowmelt as computed from recession curve analysis of recorded hydrograph.

RUNOFF (continued)

CUBIC FEET PER SECOND

June 3
June 2
June 1
(MAY 15)

12 mdnt. JUNE	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30 JUNE	1 JULY	2	3	4	5	6	7	8	9	10	11 JULY

COOPERATIVE SNOW INVESTIGATIONS

UNITED STATES DEPARTMENT OF AGRICULTURE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING, HYDROLOGY DIVISION

1948 SNOWMELT RUNOFF AND RELATED METEOROLOGICAL FACTORS

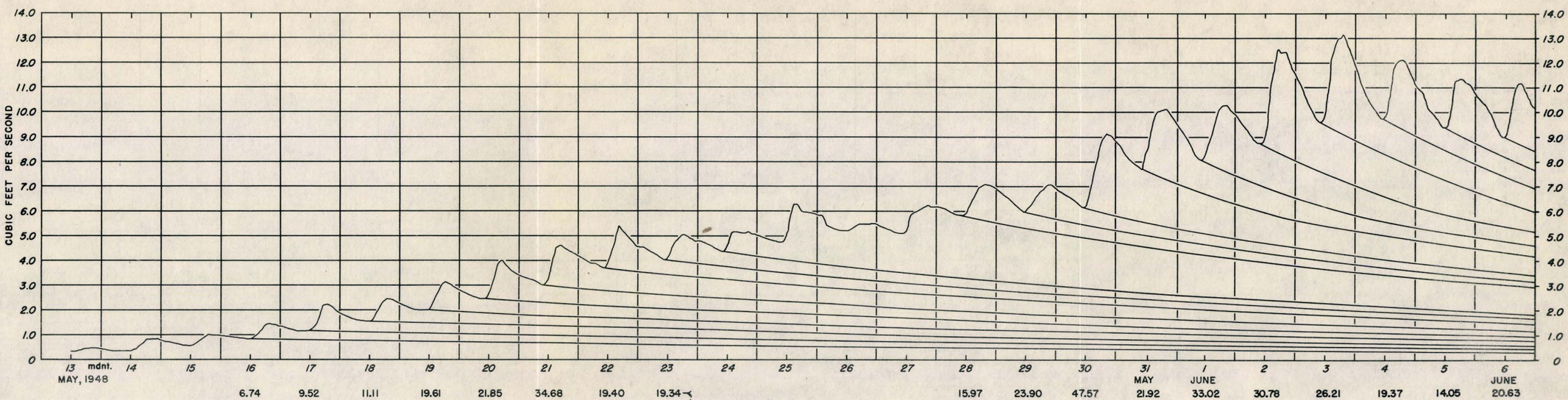
ST. LOUIS CREEK
AREA 32.8 SQUARE MILES

FRASER EXPERIMENTAL FOREST, COLORADO

April 8, 1949

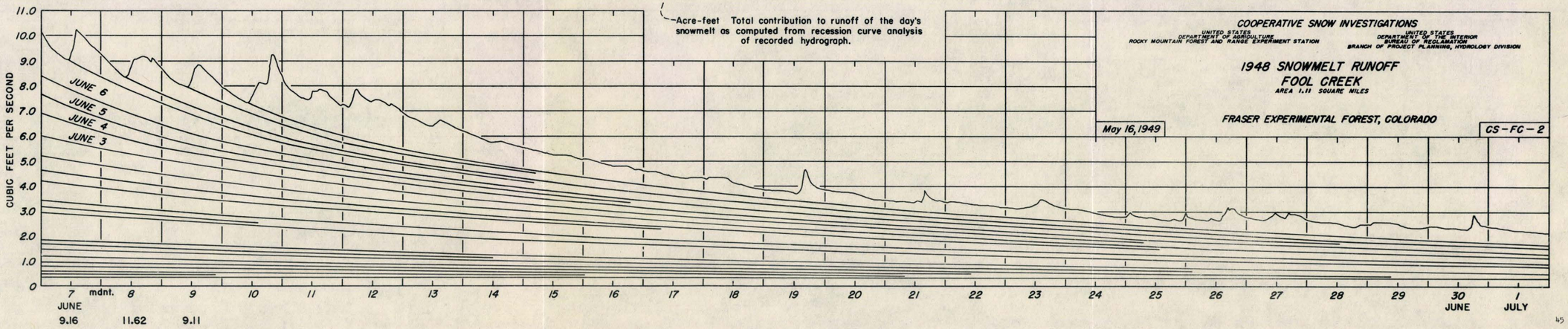
CS-SLC-23

RUNOFF RECORDED AT FOREST SERVICE GAGING STATION ON FOOL CREEK, FRASER EXPERIMENTAL FOREST, COLORADO



Acre-feet Total contribution to runoff of the day's snowmelt as computed from recession curve analysis of recorded hydrograph.

RUNOFF (continued)



COOPERATIVE SNOW INVESTIGATIONS

UNITED STATES DEPARTMENT OF AGRICULTURE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

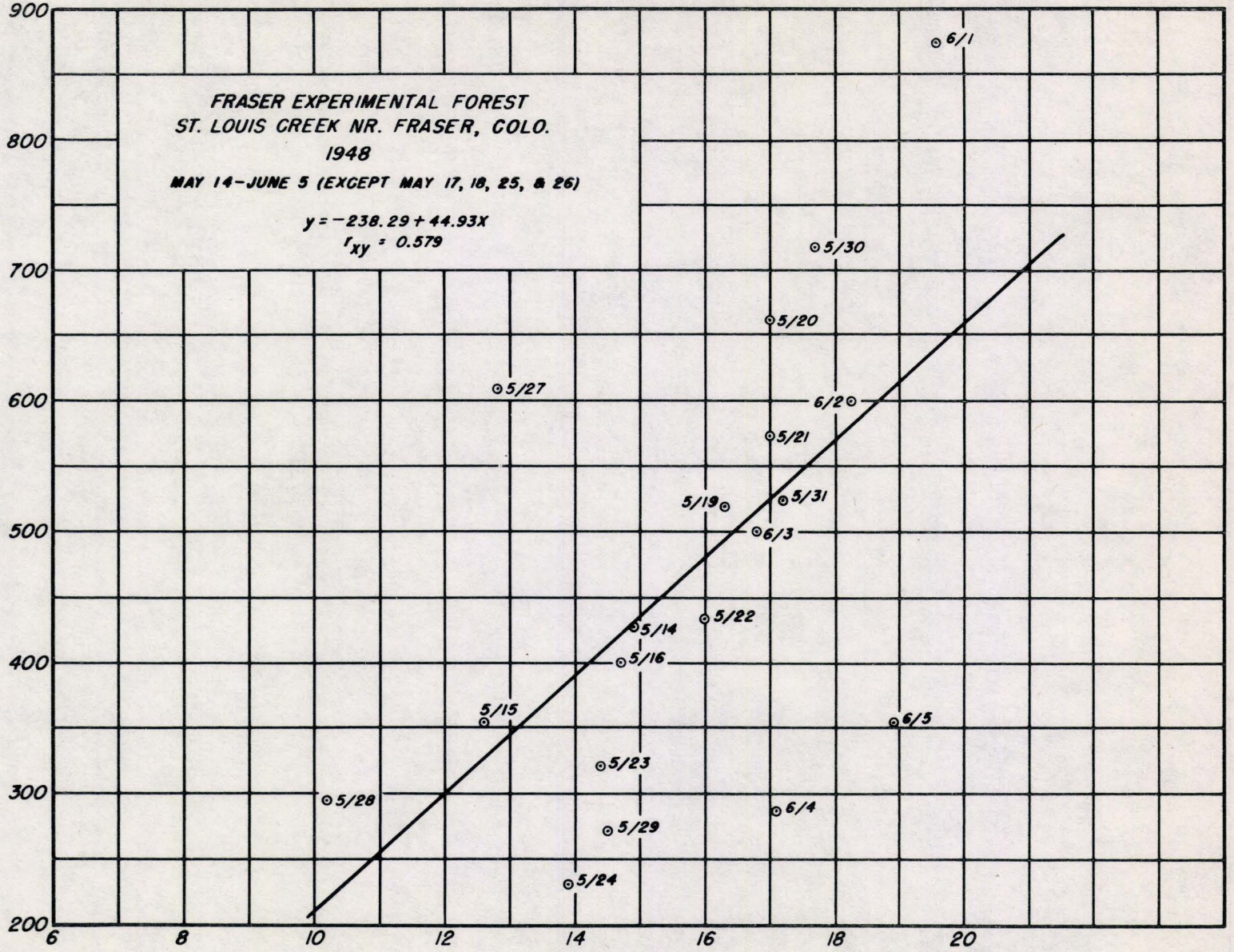
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING, HYDROLOGY DIVISION

1948 SNOWMELT RUNOFF
FOOL CREEK
AREA 1.11 SQUARE MILES

FRASER EXPERIMENTAL FOREST, COLORADO

May 16, 1949

CS-FC-2



P.P.
2-18-49
CS-SLC-9

PHILLIP LIGHT'S EQUATION*

A. General statement:

$$D = \frac{\rho k_0^2}{80 \ln(a/z_0) \ln(b/z_0)} U \left[c_p T + (e - 6.11)\, 423/p\right]$$

in cgs units

D = effective snowmelt
ρ = density of air
k_0 = von Karman's coefficient = 0.38
$\ln$ = natural logarithm
a = elevation of anemometer in mb at hygrothermograph level
z_0 = roughness parameter = 0.25
b = elevation of hygrothermograph
U = wind velocity at anemometer level
c_p = specific heat of air at constant pressure = 0.24
T = air temperature at hygrothermograph level
e = vapor pressure of air
p = atmospheric pressure in mb

B. As reduced and applied to Fraser Experimental Forest data:

$$D = KU_M \left[0.00175(T_F - 32)10^{-0.0000156h} + 0.00550(e - 6.11)\right]$$

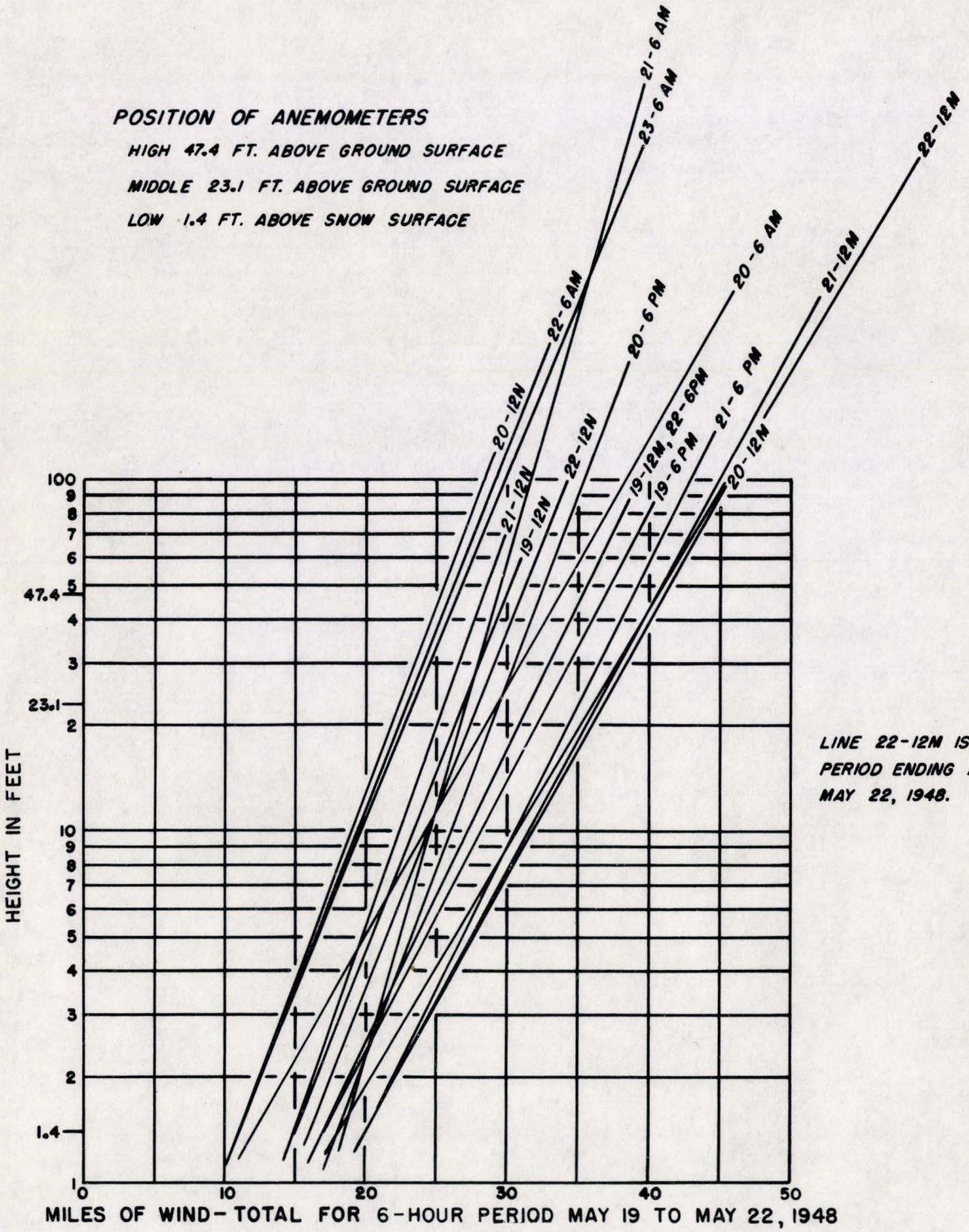
D = effective snowmelt in inches per six hours
K = basin coefficient
U_M = average wind velocity in miles per hour at fifty foot level
T_F = average air temperature in degrees F. at 7.5 foot level
h = station elevation in feet above sea level
e = average vapor pressure in mb at 7.5 foot level
6.11 = vapor pressure in mb at 32° F. dew point

$$D = KU_M \left[0.0012(T_F - 32) + 0.0055(e - 6.11)\right]$$

*Light, Phillip, "Analysis of High Rates of Snow-Melting," Transactions, American Geophysical Union, Part I, 1941, pp. 195-205.

WIND IN RELATION TO HEIGHT
AS OBSERVED AT WIND TOWER IN THE OPEN

WEST ST. LOUIS CREEK
FRASER EXPERIMENTAL FOREST,
COLORADO
1948



LINE 22-12M IS FOR 6-HOUR PERIOD ENDING AT 12 MIDNIGHT MAY 22, 1948.

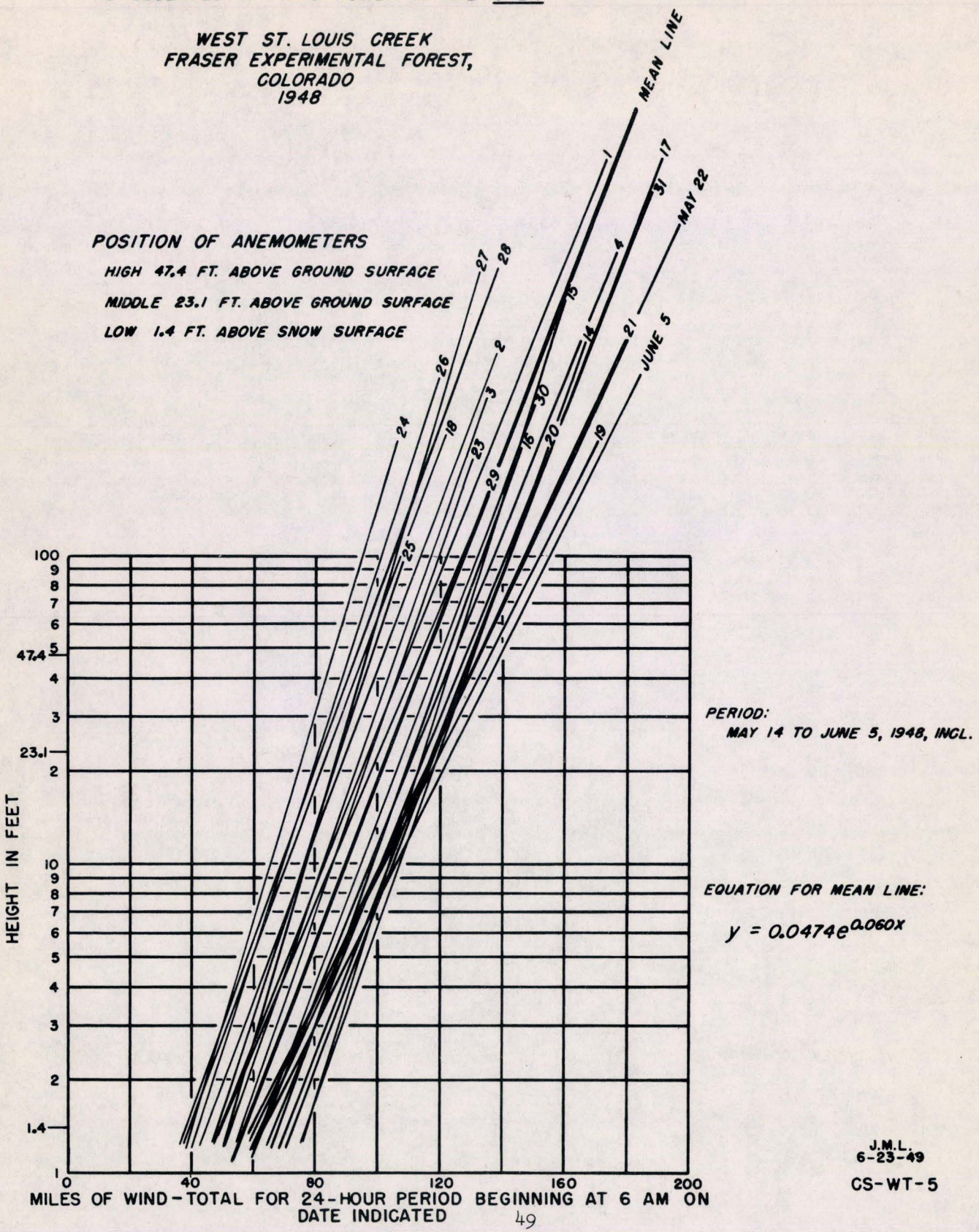
J.M.L.-P.P.
6-23-49

CS-WT-4

WIND IN RELATION TO HEIGHT

AS OBSERVED AT WIND TOWER IN THE OPEN

WEST ST. LOUIS CREEK
FRASER EXPERIMENTAL FOREST,
COLORADO
1948

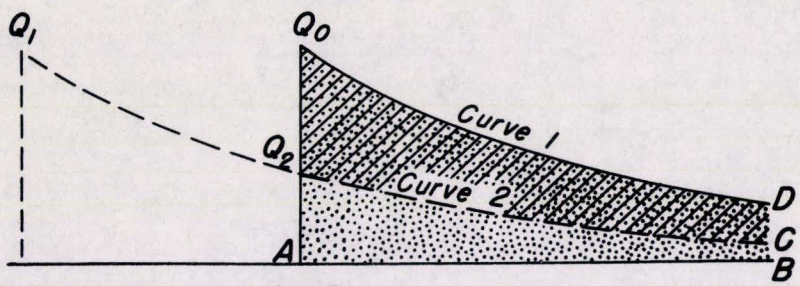


RECESSION OF HYDROGRAPH

(Considering nearest whole day - approximate area)

$$Q = Q_0 K^t$$

$$R = \int Q\,dt = \int Q_0 K^t dt = Q_0 \frac{K^t}{\log_e K}$$



Area Q_0ABD: $$Q_0 \frac{K^t}{\log_e K}\Bigg|_0^{t_1} = Q_0\left[\frac{K^{t_1}}{\log_e K} - \frac{K^0}{\log_e K}\right]$$

Area Q_2ABC: $$Q_1 \frac{K^t}{\log_e K}\Bigg|_1^{t_1+1} = Q_1\left[\frac{K^{t_1+1}}{\log_e K} - \frac{K}{\log_e K}\right]$$

Difference: $$R = Q_0\left[\frac{K^{t_1}-1}{\log_e K}\right] - Q_1\left[\frac{K^{t_1+1}-K}{\log_e K}\right] = \frac{Q_0(K^{t_1}-1) - Q_1(K^{t_1+1}-K)}{\log_e K} =$$

$$\frac{Q_0(K^{t_1}-1) - KQ_1(K^{t_1}-1)}{\log_e K} \quad \text{or} \quad \frac{(Q_0 - KQ_1)(K^{t_1}-1)}{\log_e K}$$

t is time in days

$KQ_1 = Q_2$ for whole days

P.M.F.
3-11-47

CS-T5

Forest Service
Department of
Agriculture

Rocky Mountain Forest
and Range Experiment
Station

TABLE CS-SLC-T15
SUMMARY SHEET

MULTIPLE CORRELATION ANALYSES
SHOWING REGRESSION COEFFICIENTS OBTAINED AND EQUATIONS DERIVED
ST. LOUIS CREEK NEAR FRASER, COLORADO
Area = 33 Square Miles
1948 Snowmelt Season

Bureau of Reclamation
Department of the
Interior

Hydrology Division
Branch of Project
Planning

X_1 Computed volume of melt for day--10 acre-feet
X_2 Degree-days above 32° F at Fraser Hqrs--10° days
X_3 Degree-days above 50° F at Fraser Hqrs--10° days
X_4 Solar radiation at Shadow Mountain--10 g-cal/cm^2/min.
X_5 Dew point temperatures at Fraser Headquarters--10°
X_6 Relative humidity at Fraser Hqrs--10%
X_7 Wind at 47.4' level in Open--100 miles of wind
X_8 Wind at 1.4' level in Forest--100 miles of wind
X_9 Wind at 24.9' level in Forest--100 miles of wind

For May 20, 1948
X_2 = 1.70 X_6 = 5.37
X_3 = 0.56 X_7 = 1.32
X_4 = 54.57 X_8 = 0.33
X_5 = 2.87 X_9 = 0.21

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	$\bar{R}$	$\bar{S}$	Data for May 20 substituted in equation:	Equation Designation
$X_{1.2457}$	47.710		-0.373	14.111		24.310			.682	12.576	$X_1 = 47.710(1.70) - 0.373(54.57) + 14.111(2.87) + 24.310(1.32) - 71.22$ $X_1 = 62.13$	a
$X_{1.257}$	38.001			22.590		24.828			.675	12.692	$X_1 = 38.001(1.70) + 22.590(2.87) + 24.828(1.32) - 106.26$ $X_1 = 55.94$	b
$X_{1.3457}$		-3.377	0.081	29.434		57.450					$X_1 = -3.377(.56) + 0.081(54.57) + 29.434(2.87) + 57.450(1.32) - 107.30$ $X_1 = 55.54$	c
$X_{1.2467}$	70.589		-0.419		9.126	18.920			.695	12.367	$X_1 = 70.589(1.70) - 0.419(54.57) + 9.126(5.37) + 18.920(1.32) - 110.19$ $X_1 = 60.93$	d
$X_{1.267}$	72.585				14.145	13.559			.736	11.646	$X_1 = 72.585(1.70) + 14.145(5.37) + 13.559(1.32) - 164.73$ $X_1 = 52.52$	e
$X_{1.3467}$		545.756	-6.855		-83.471	-338.271					$X_1 = 545.756(.56) - 6.855(54.57) - 83.471(5.37) - 338.271(1.32) + 1,123.69$ $X_1 = 160.47$	f
$X_{1.2468}$	72.296		-0.412		8.061		20.173		.681	12.595	$X_1 = 72.296(1.70) - 0.412(54.57) + 8.061(5.37) + 20.173(.33) - 91.71$ $X_1 = 58.66$	g
$X_{1.268}$	74.793				13.115		6.000		.658	12.943	$X_1 = 74.793(1.70) + 13.115(5.37) + 6.000(.33) - 148.54$ $X_1 = 51.02$	h
$X_{1.274}$	58.233		-0.645			13.412			.531	14.575	$X_1 = 58.233(1.70) - 0.645(54.57) + 13.412(1.32) - 16.25$ $X_1 = 61.25$	i
$X_{1.27}$	47.867					-5.289			.511	14.787	$X_1 = 47.867(1.70) - 5.289(1.32) - 22.39$ $X_1 = 52.00$	j

TABLE CS-FC-T4

COOPERATIVE SNOW INVESTIGATIONS

Forest Service
Department of
Agriculture

Rocky Mountain Forest
and Range Experiment
Station

COMPARISON OF SNOW MELTS

Fool Creek, Colorado
Area = 1.1 square miles

1948 Snowmelt Season

Bureau of Reclamation
Department of the
Interior

Hydrology Division
Branch of Project
Planning

1948 Date	Snowmelt Runoff			Percent departure of equation from hydrograph computed volumes	
	Calculated by Equation*	Computed from hydrograph	Difference	By days	By groups of 3 days
	Inches Depth			%	
May 16	0.134	0.114	+.020	+17.5	
19	0.487	0.332	+.155	+46.7	
20	0.369	0.370	-.001	- 0.3	+21.3
21	0.422	0.587	-.165	-28.1	
22	0.258	0.328	-.070	-21.3	
23	0.167	0.327	-.160	-48.9	-31.8
28	0.168	0.270	-.102	-37.8	
29	0.119	0.404	-.285	-70.5	
30	0.455	0.805	-.350	-43.5	-49.8
31	0.439	0.371	+.068	+18.3	
June 1	0.491	0.559	-.068	-12.2	
2	0.524	0.521	+.003	+ 0.6	+ 0.2
3	0.262	0.444	-.182	-41.0	
4	0.207	0.328	-.121	-36.9	
5	0.379	0.238	+.141	+59.2	-16.0
TOTALS	4.881	5.998		Average of daily departures, based on hydrograph computed volumes 32.2 percent	
DIFFERENCE	-1.117				
Percentage of departure of equation computed snowmelt, from hydrograph computed snowmelt	-18.6 percent				
Total of daily differences summed without regard to sign			1.891		
Percentage departure of above total from hydrograph-computed total				31.5 percent	
Average percentage departure for five groups of three days each					23.8 percent

* Sum of four six-hour periods, taking into account a six-hour lag time.

COMPUTATION OF SNOWMELT BY LIGHT'S EQUATION

$$D \doteq U_M [0.00175^{*}(T_F - 32)10^{-0.0000156h} + 0.00550^{*}(e - 6.11]$$

WHERE: D = effective snowmelt in inches per six hours
U_M = average wind velocity in miles per hour - 50'level
T_F = air temperature in degrees Fahrenheit
e = vapor pressure in millibars
h = station elevation above sea level in feet (10,500')

SUBSTITUTING VALUE OF h AND REDUCING:

$$D = U_M [0.00175(T_F - 32)0.6858 + 0.00550(e - 6.11]$$
$$= U_M [0.0012(T_F - 32) + 0.00550(e - 6.11]$$

1948 Date	6-Hour Period Ending At		Total for 24-Hour Period	EFFECTIVE DATE With Time Lag For ST. LOUIS CREEK
May 14	6 A.M.	Example of substitution of values: D = 4.67 [0.0012(37.17 - 32) + 0.00550(3.15 - 6.11)] D = 4.67(0.0062 - 0.0163) = -0.047		
	12 Noon	D = 7.00(0.0274 - 0.0170) = 0.073		
	6 P.M.	D = 5.83(0.0266 - 0.0144) = 0.071		
	12 Mdnt.	D = 5.33(0.0 - 0.0043) = -0.023		
May 15	6 A.M.	D = 3.50(0.0038 - 0.0144) = -0.064	0.144	May 14
	12 Noon	D = 5.17(0.0236 - 0.0178) = 0.030		
	6 P.M.	D = 4.83(0.0248 - 0.0163) = 0.041		
	12 Mdnt.	D = 6.67(0.0020 - 0.0083) = -0.069		

* Constants have been corrected because the temperature and relative humidity are measured at about the 7.5' instead of 10' level.

TABLE CS-SLC-T11

Forest Service
Department of
Agriculture

Rocky Mountain Forest
and Range Experiment
Station

COOPERATIVE SNOW INVESTIGATIONS

COMPARISON OF SNOW MELTS

ST. LOUIS CREEK, COLORADO
Area = 33 square miles

1948 Snowmelt Season

Bureau of Reclamation
Department of the
Interior

Hydrology Division
Branch of Project
Planning

1948 Date	Snowmelt Runoff			Percent departure of equation from hydrograph computed volumes	
	Calculated by Equation*	Computed from hydrograph	Difference	By days	By groups of 3 days
	Inches Depth			%	
May 14	0.144	0.244	-.100	-41.0	
15	0.071	0.202	-.131	-64.8	
16	0.134	0.229	-.095	-41.5	-48.3
19	0.487	0.297	+.190	+64.0	
20	0.369	0.379	-.010	- 2.6	
21	0.422	0.328	+.094	+28.6	+27.3
22	0.258	0.248	+.010	+ 4.0	
23	0.167	0.184	-.017	- 9.2	
24	0.227	0.132	+.095	+72.0	+15.6
27	0.208	0.348	-.140	-40.2	
28	0.168	0.169	-.001	- 0.6	
29	0.119	0.155	-.036	-23.2	-26.3
30	0.455	0.410	+.045	+11.0	
31	0.439	0.299	+.140	+46.8	
June 1	0.491	0.500	-.009	- 1.8	+14.6
2	0.524	0.343	+.181	+52.8	
3	0.262	0.286	-.024	- 8.4	
4	0.207	0.164	+.043	+26.2	+25.2
5	0.379	0.202	+.177	+87.6	
TOTALS	5.531	5.119		Average of daily departures, based on hydrograph computed volumes 33.0 percent	
DIFFERENCE	+0.412				
Percentage of departure of equation computed snowmelt, from hydrograph computed snowmelt	+8.0 percent				
Total of daily differences summed without regard to sign			1.538		
Percentage departure of above total from hydrograph-computed total				30.0 percent	
Average percentage departure for six groups of three days each					26.2 percent

* Sum of four six-hour periods, taking into account lag time.

3-29-49

TABLE CS-SLC-T17

COMPARISON OF DAILY SNOWMELT RUNOFFS
ST. LOUIS CREEK, COLORADO - Area 33 square miles

1948 Date	RUNOFF-INCHES DEPTH		
	Computed from hydrograph	Calculated by Light's equation	Calculated using multiple-correlation equation (e) correl. coeff. $R_{x1.267}=0.736$
May 14	0.244	0.144	0.154
15	0.202	0.071	0.099
16	0.229	0.134	0.210
19	0.297	0.487	0.286
20	0.379	0.369	0.300
21	0.328	0.422	0.328
22	0.248	0.258	0.242
23	0.184	0.167	0.233
24	0.132	0.227	0.230
27	0.348	0.208	0.207
28	0.169	0.168	0.181
29	0.155	0.119	0.217
30	0.410	0.455	0.364
31	0.299	0.439	0.373
June 1	0.500	0.491	0.394
2	0.343	0.524	0.432
3	0.286	0.262	0.271
4	0.164	0.207	0.232
5	0.202	0.379	0.350
TOTAL	(A) 5.119	(B) 5.531	(C) 5.103
DIFFERENCE	B-A = 0.412"		C-A = -0.016"
Departure from hydrograph computed total		8.0%	-0.3%
Coefficients of correlation with reference to hydrograph computed totals		r_{xy} = 0.720	r_{xy} = 0.663

APPENDIX V

EVAPORATION LOSSES

Tables			Page
CS-SLC-T24	1948	Daily Totals of Evaporation Loss Computed by Light's Equation.	57
CS-SLC-T29	1949	Daily Totals of Evaporation Loss Computed by Light's Equation.	57

TABLE CS-SLC-T24

COOPERATIVE SNOW INVESTIGATIONS

Forest Service
Department of
Agriculture

EVAPORATION FROM SNOW
COMPUTED BY LIGHT'S EQUATION

Bureau of Reclamation
Department of the
Interior

Rocky Mountain Forest
and Range Experiment
Station

ST. LOUIS CREEK, COLORADO
Area = 32.8 square miles

Hydrology Division
Branch of Project
Planning

1948 Snowmelt Season

	Total Inches for 24-Hour Period Including Lag Time for St. Louis Creek Calculated Value Adjusted by Basin Coefficient 0.926	
1948 Date	Exclusive of Periods Having Avg. Temp. Below 32° F.	Including Periods of Avg. Temp. Below 32° F.**
May 14*	0.209	0.255
15*	0.158	0.255
16	0.151	0.151
18	0.010	0.010
19	None	None
20	0.065	0.065
21	0.087	0.087
22*	0.151	0.169
23	0.036	0.036
24	0.012	0.012
27	0.056	0.056
28	0.025	0.025
29*	0.137	0.157
30	0.057	0.057
31	0.035	0.035
June 1	0.012	0.012
2	None	None
3	0.113	0.113
4	0.172	0.172
5	0.120	0.120
Total	1.606	1.787

*Days for which there is at least one 6-hour period having avg. temp. below 32° F.

**Not corrected for vapor pressure corresponding to avg. temp. dew point.

TABLE CS-SLC-T29

COOPERATIVE SNOW INVESTIGATIONS

Forest Service
Department of
Agriculture

EVAPORATION FROM SNOW
COMPUTED BY LIGHT'S EQUATION

Bureau of Reclamation
Department of the
Interior

Rocky Mountain Forest
and Range Experiment
Station

ST. LOUIS CREEK, COLORADO
Area 32.8 square miles

Hydrology Division
Branch of Project
Planning

1949 Snowmelt Season

	Total Inches for 24-Hour Period Including Lag Time for St. Louis Creek, Calculated Value Adjusted by Basin Coefficient 0.926	
1949 Date	Exclusive of Periods Having Avg. Temp. Below 32° F.	Including Periods of Avg. Temp. Below 32° F.**
May 19*	0.140	0.219
20	0.161	0.161
21*	0.020	0.024
22	0.041	0.041
23*	0.149	0.155
24*	0.132	0.147
25*	0.153	0.154
26*	0.099	0.105
27	0.033	0.033
June 1*	0.035	0.055
2*	0.087	0.094
3	0.054	0.054
4	None	None
5	0.078	0.078
6	None	None
7	None	None
8	None	None
9	None	None
10	0.006	0.006
15	0.104	0.104
16	0.010	0.010
17	None	None
18	None	None
19	0.028	0.028
20	0.117	0.117
Total	1.441	1.585

*Days for which there is at least one 6-hour period having avg. temp. below 32° F.

**Not corrected for vapor pressure corresponding to avg. temp. dew point.

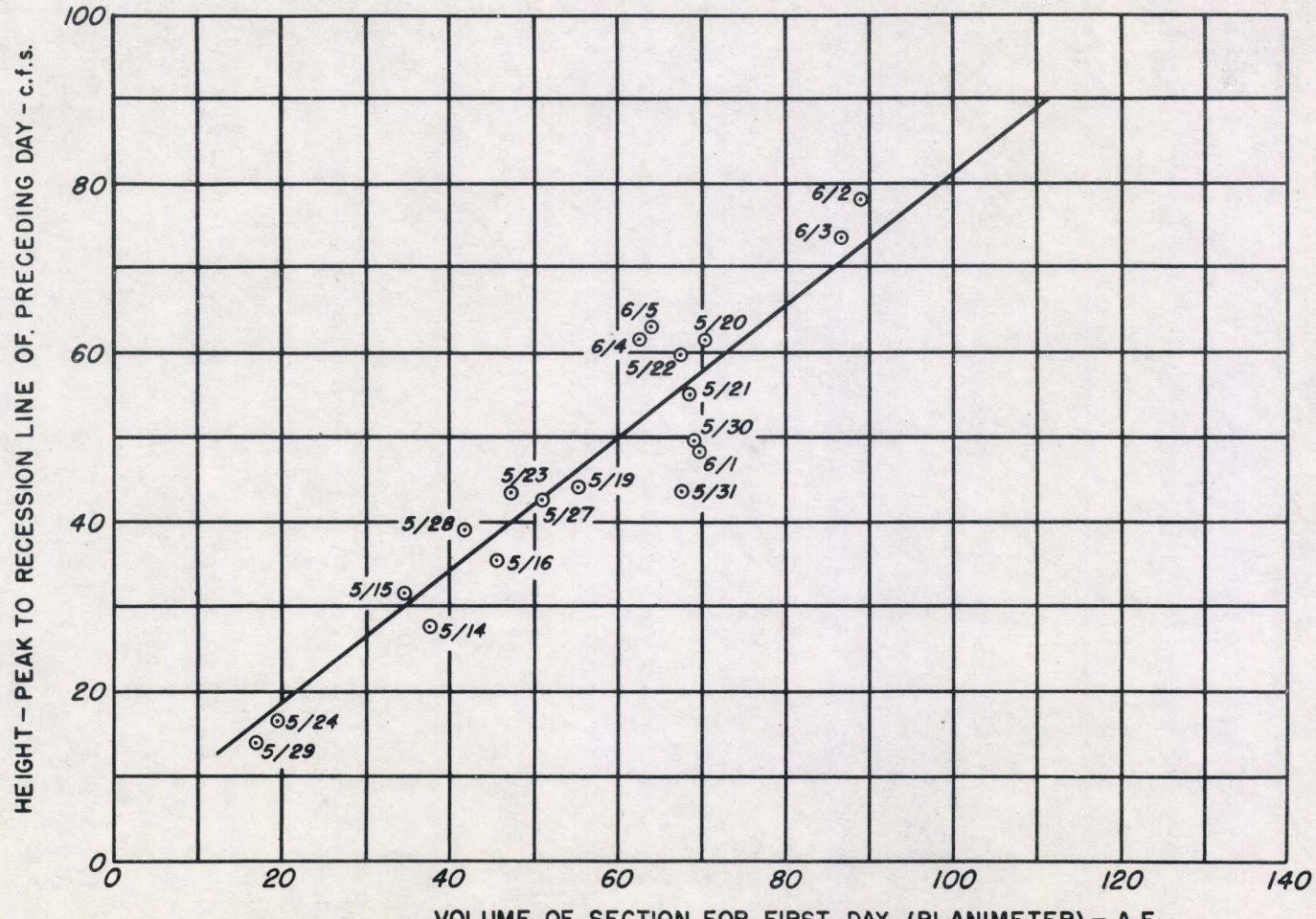
APPENDIX VI

SYNTHESIS OF SNOWMELT HYDROGRAPH

Charts		Page
CS-SLC-10	Volume of melt on first day vs. Height - Peak to Recession Line of Preceding Day, May 14-June 5, 1948.	59
CS-SLC-25	Volume of melt on first day vs. Height - Trough to Recession Line of Preceding Day, May 14-June 5, 1948.	60
CS-SLC-24	Total Computed Melt for One Day vs. Volume of Melt on First Day, May 14-June 5, 1948.	61
CS-SLC-27	Method of Synthesizing Snowmelt Hydrograph.	62
CS-SLC-26	Comparison of Observed and Computed Hydrographs, 1948.	63
CS-SLC-34	Comparison of Observed and Forecasted Hydrographs, 1949.	64
CS-SLC-T33	1949 Forecasted Total Daily Contribution to Runoff--St. Louis Creek.	65

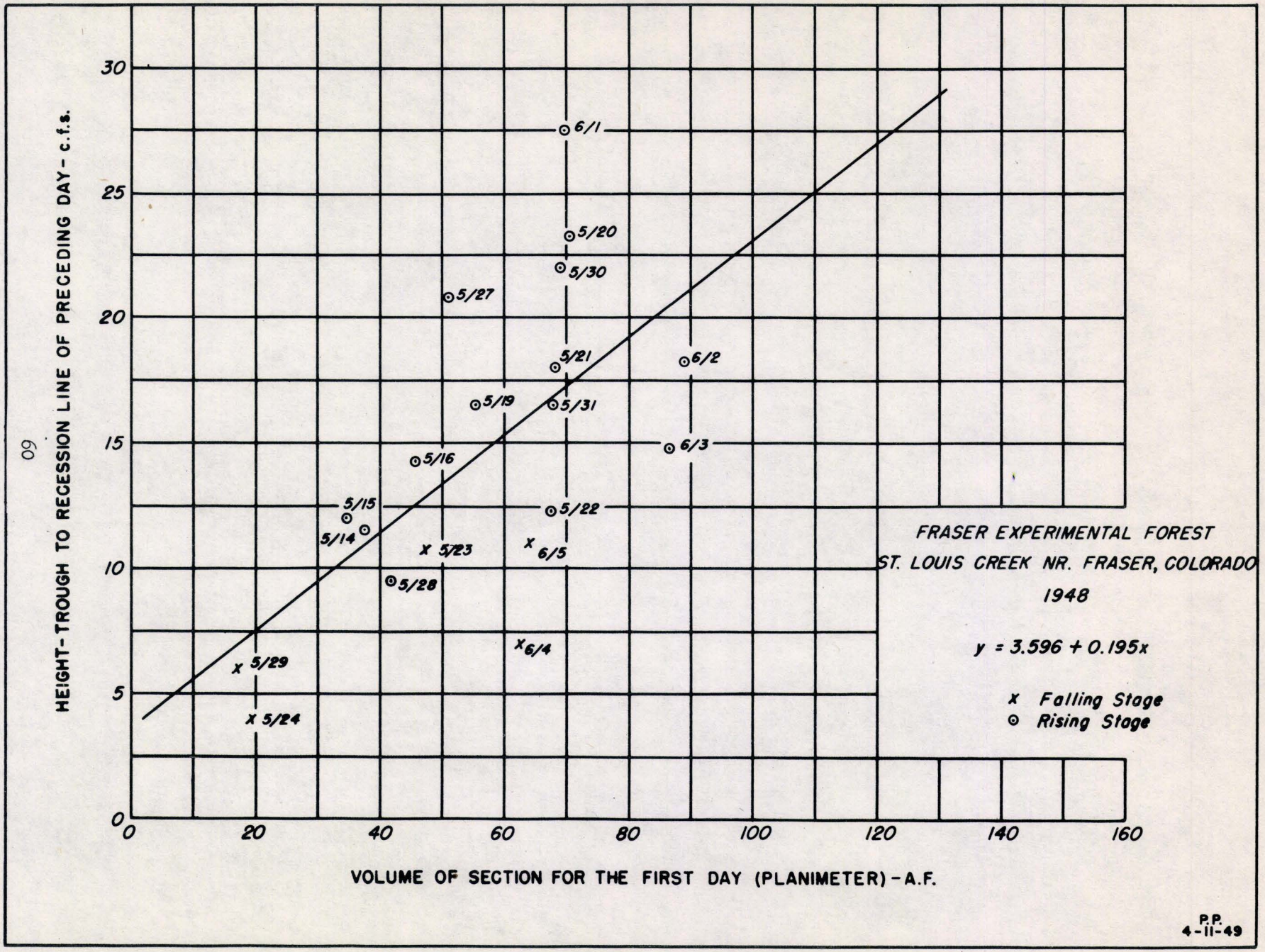
FRASER EXPERIMENTAL FOREST
ST. LOUIS CREEK NR. FRASER, COLORADO
1948

$y = 3.291 + 0.780x$

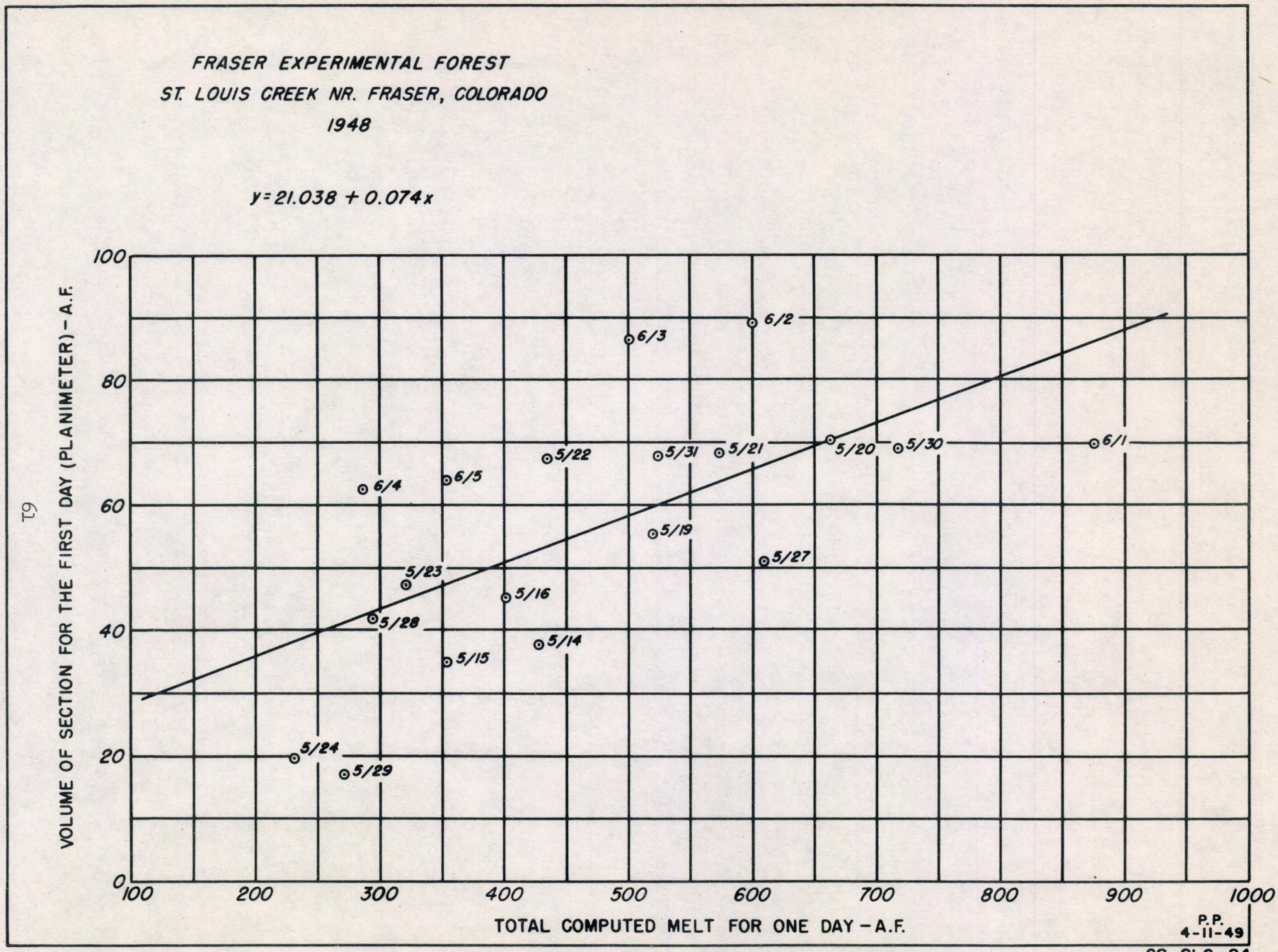


P.P.
4-11-49

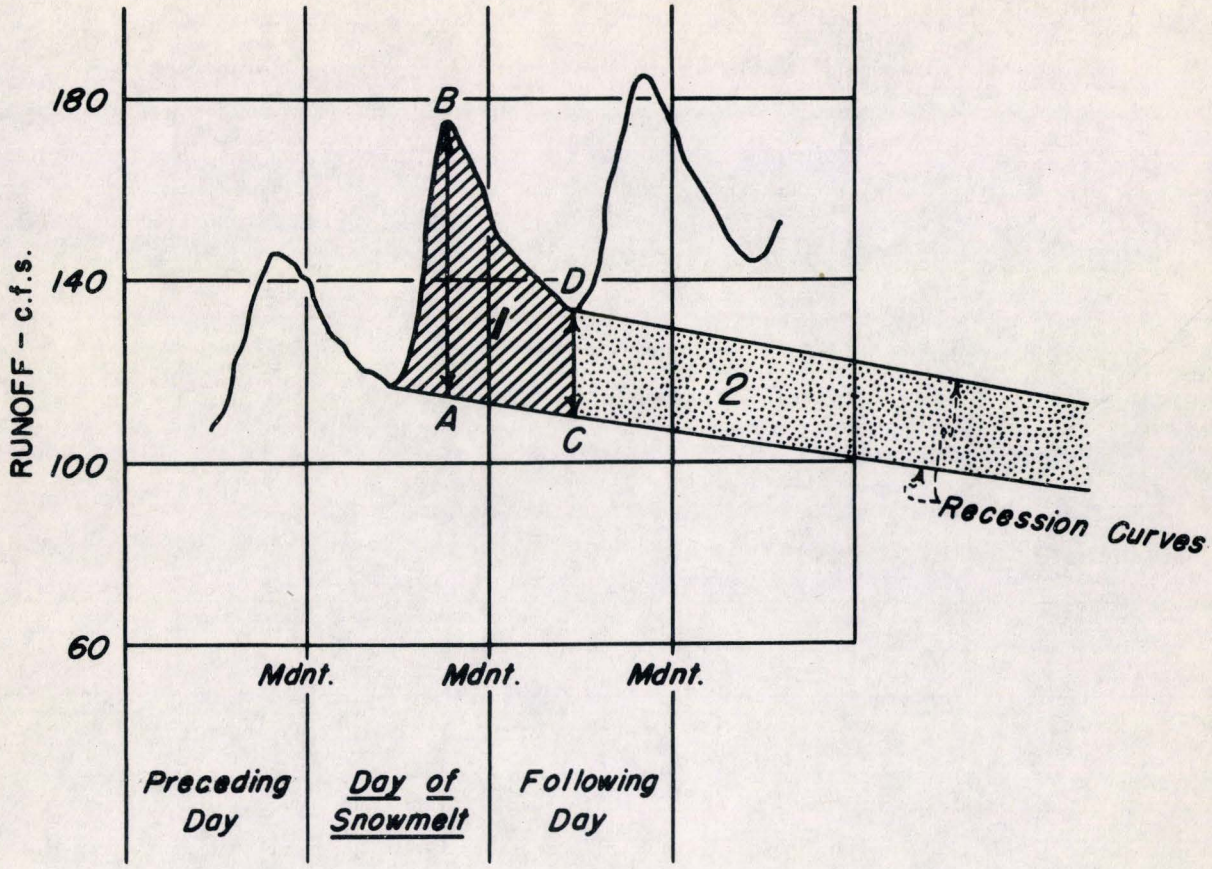
CS-SLC-10


HEIGHT-TROUGH TO RECESSION LINE OF PRECEDING DAY - c.f.s.
VOLUME OF SECTION FOR THE FIRST DAY (PLANIMETER) - A.F.
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160
6/1
5/20
5/30
5/27
5/21
6/2
5/19
5/31
6/3
5/16
5/15
5/22
5/14
5/23
6/5
5/28
6/4
5/29
5/24
FRASER EXPERIMENTAL FOREST
ST. LOUIS CREEK NR. FRASER, COLORADO
1948
y = 3.596 + 0.195x
x Falling Stage
⊙ Rising Stage
P.P.
4-11-49

CS-SLC-25


FRASER EXPERIMENTAL FOREST
ST. LOUIS CREEK NR. FRASER, COLORADO
1948
y = 21.038 + 0.074x
VOLUME OF SECTION FOR THE FIRST DAY (PLANIMETER) - A.F.
TOTAL COMPUTED MELT FOR ONE DAY - A.F.
0
20
40
60
80
100
100
200
300
400
500
600
700
800
900
1000
6/2
6/3
6/1
5/20
5/30
5/21
5/31
5/22
6/5
6/4
5/19
5/27
5/23
5/16
5/28
5/14
5/15
5/24
5/29
P.P.
4-11-49
CS-SLC-24

METHOD OF COMPUTATION OF SNOWMELT HYDROGRAPH



Area 1 = Volume of a day's snowmelt appearing in the first 24-hour period.

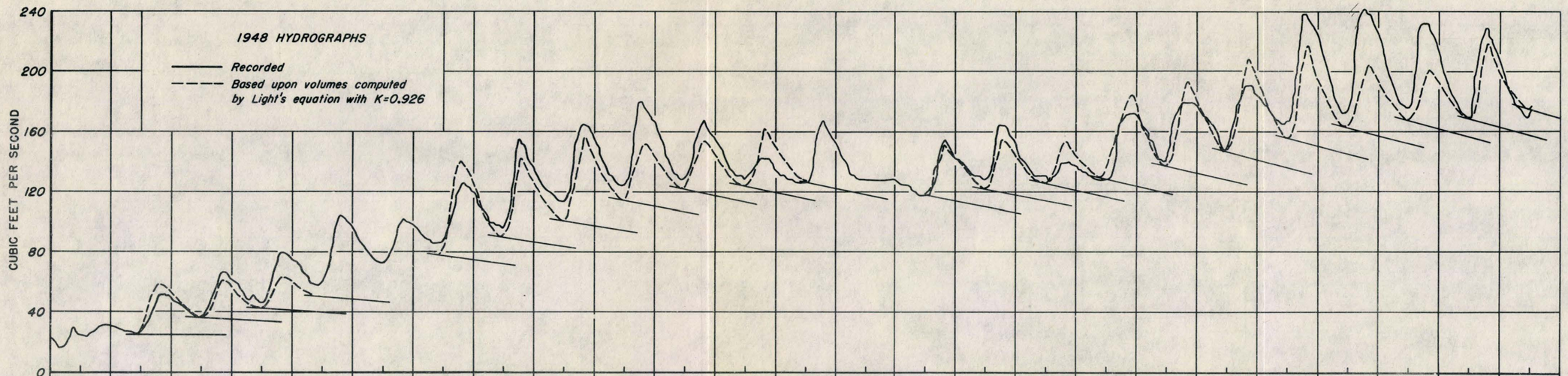
Area 2 = Volume of a day's snowmelt in recession flow.

Total snowmelt for the day calculated by equation = Area 1 + Area 2.

Area 1 derived from Chart CS-SLC-24.
Distance A-B derived from Chart CS-SLC-10
Distance C-D derived from Chart CS-SLC-25

W.U.G.
4-14-49
CS-SLC-27

COMPARISON OF RECORDED AND COMPUTED HYDROGRAPHS



St. Louis Creek near Fraser, Colorado
Area - 32.8 Square Miles

Hydrograph synthesized using procedure shown on Chart CS-SLC-27

	13 MAY 1948	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 MAY	1 JUNE	2	3	4	5	6	
Acre-Feet		428	354	401			519	663	574	434	321	232			609	295	272	718	524	875	600	500	287	354		Total daily snowmelt from hydrograph.
Acre-Feet		233	115	217			789	598	684	418	271	368			337	272	193	737	711	795	849	424	335	614		Total daily snowmelt by Light's equation.

W.U.G.
4-11-49

CS-SLC-26

COMPARISON OF RECORDED AND FORECASTED HYDROGRAPHS

1949 SNOW-MELT SEASON

1949 HYDROGRAPHS

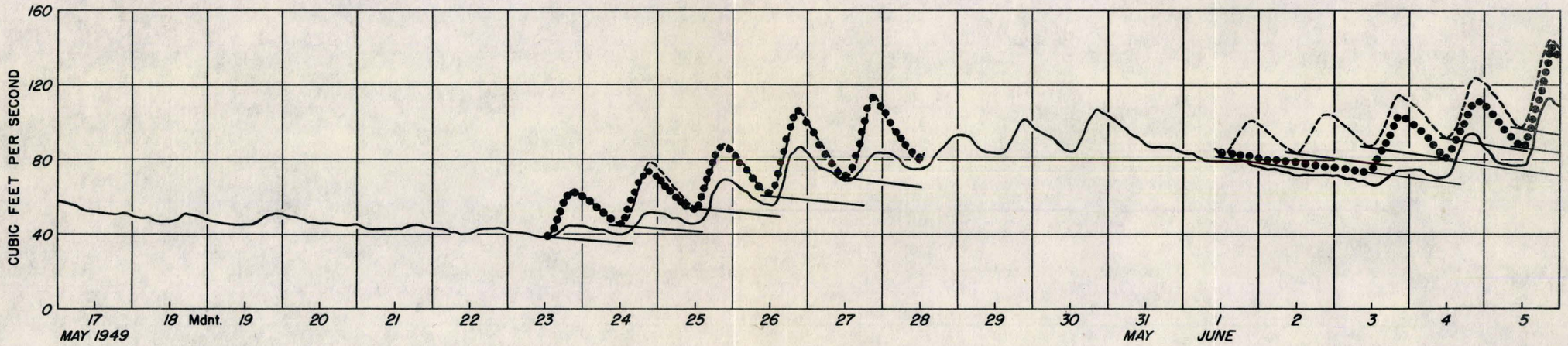
Hydrograph synthesized by using Light's equation with K = 0.926 as determined for the 1948 season and using charts CS-SLC-24,-25, and -10. Synthesized only for periods for which records of wind, temperature, and humidity are available at the wind tower in the open. See text.

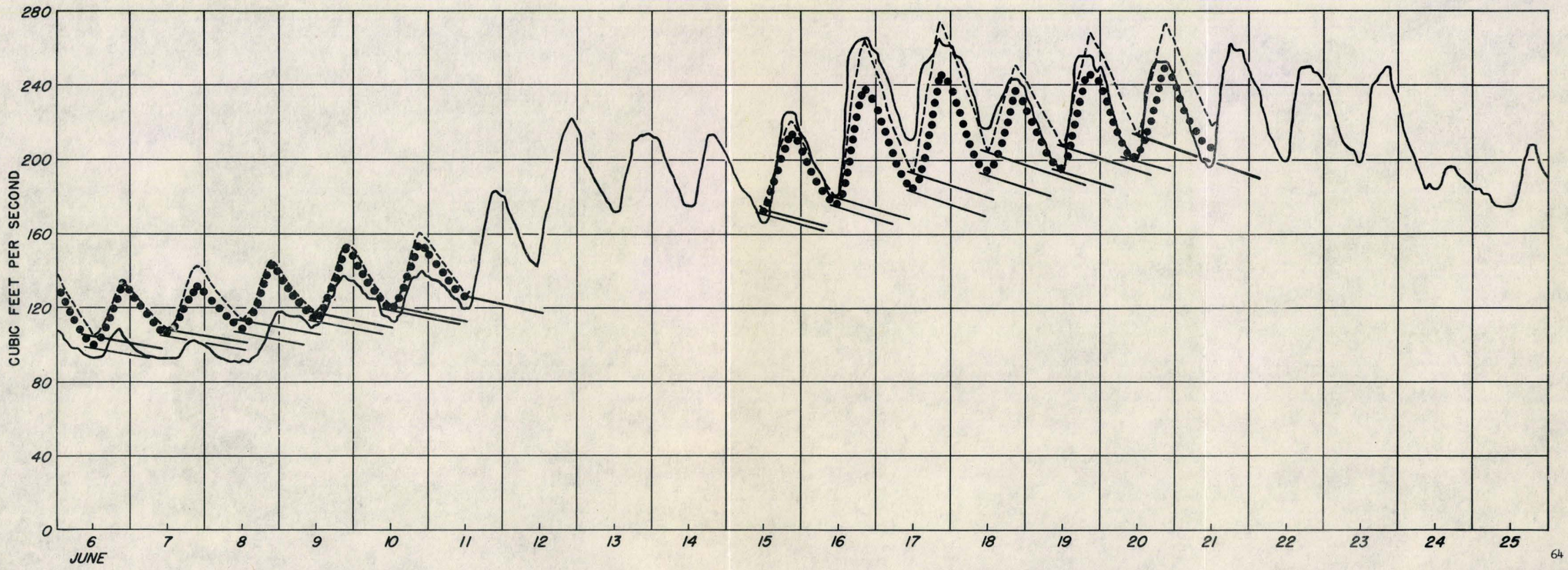
Observed hydrograph, from U.S.G.S. gaging station, St. Louis Creek. Preliminary computation using temporary rating table dated 7-29-49.

Hydrograph synthesized by using Equation "6" from table CS-SLC-T15 as derived for the 1948 season and using charts CS-SLC-24,-25, and -10.

St. Louis Creek Near Fraser, Colorado
Area - 32.8 Square Miles

Hydrograph synthesized using procedure shown on Chart CS-SLC-27





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J.M.L.-P.P.-W.U.G.
NOV. 22, 1949

CS-SLC-34

TABLE CS-SLC-T33

COOPERATIVE SNOW INVESTIGATIONS

1949 FORECASTED TOTAL DAILY CONTRIBUTIONS TO RUNOFF

ST. LOUIS CREEK, COLORADO

1949 Date	Calculated by Light's Equation using K = 0.926 as derived for 1948. Acre Feet	Calculated using Multiple Correlation Equation "e", as derived for 1948. Acre Feet
May 23	122.8	105.2
24	279.6	193.9
25	243.5	304.5
26	474.5	494.9
27	473.0	439.8
June 1	19.4	0.0
2	54.1	0.0
3	181.8	227.6
4	270.7	259.8
5	527.6	628.6
6	221.4	316.9
7	302.8	204.9
8	316.4	361.3
9	357.8	443.3
10	398.2	351.2
15	550.9	508.1
16	1,253.5	845.9
17	1,140.2	872.7
18	585.4	595.3
19	807.7	689.9
20	796.2	674.8
Total	9,377.5	8,518.6